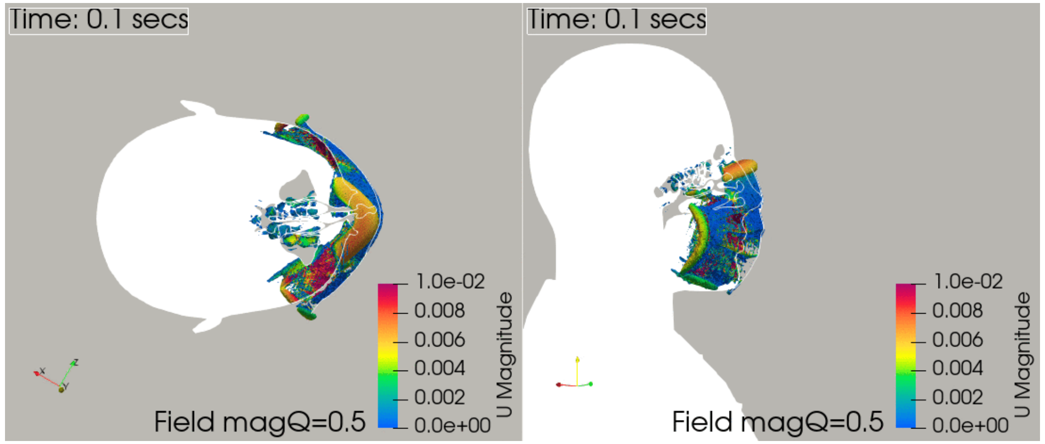
CFD helping to mitigate COVID transmission



Project Title: Opensource software simulations towards understanding, monitoring and controlling COVID-19 transmission by managing air, people distancing and adapting urban environments

Project number: 85435

Competition: UKRI Ideas to address COVID-19 – Innovate UK de minimis Aug'20

Funding body: Innovate UK

OpenCFD Limited, UK

F Mendonça, P Ghildiyal, A Heather, K Bercin,
with contributions from ESI-Group's P Sonakar, P Jaganathan, R Magg

Advanced Modeling and Simulation (AMS) Seminars Series

NASA Ames Research Center, July 15th, 2021

esi-group.com

CFD (OpenFOAM®) in the COVID-19 battle

Global acceptance of aerosol airborne transmission mechanism

- **World Health Organisation (*09-July-2020*)**

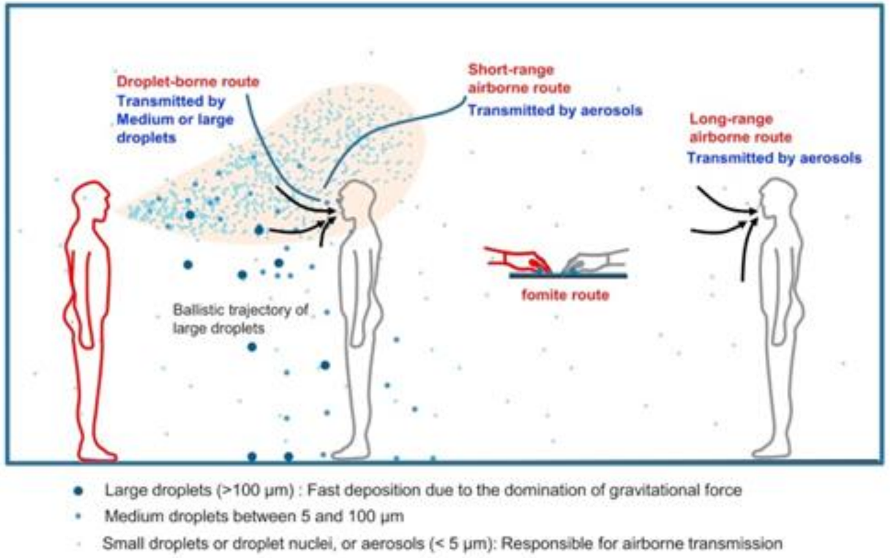
  *“**Transmission of SARS-CoV-2 can occur through direct, indirect, or close contact with infected people through infected secretions such as saliva and respiratory secretions or their respiratory droplets**, which are expelled when an infected person coughs, sneezes, talks or sings. Respiratory droplets are >5-10 μm in diameter whereas droplets ≤5μm in diameter are referred to as droplet nuclei or aerosols.”*

- **Professional Bodies**
  - **ASHRAE (*05-April-21*)**

    “Airborne transmission of SARS-CoV-2 is significant and should be controlled. Changes to building operations, including the operation of heating, ventilating, and air-conditioning systems, can reduce airborne exposures.”
  - **CIBSE with SAGE, UK (*23-Oct-2020*)**

    “Ventilation is an important factor in mitigating against the risk of far-field (>2m) aerosol transmission”
  - **IMechE (current COVID-19 Manual)**

    “Airborne transmissions can transmit small particulates through the air over time and distance. Airborne transmissions are usually distinct from transmission by respiratory droplets. Respiratory droplets are droplet particles greater than 5-10 μm in diameter whereas droplets less than 5 μm are referred to as droplet nuclei.”

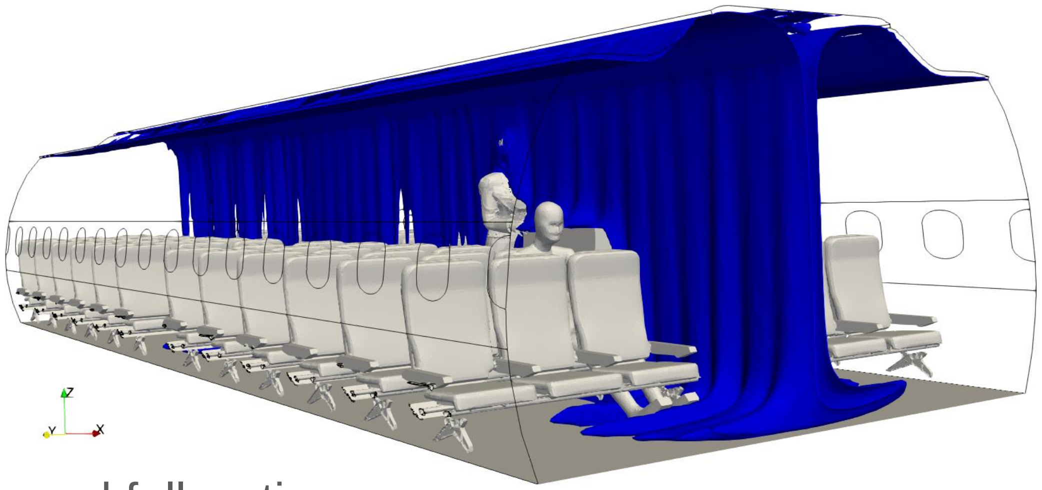


CFD (OpenFOAM®) in the COVID-19 battle

AGENDA

- **Statement of need**
  - How effective is the internal room ventilation regarding fresh/clean air circulation?
  - What happens to viral load from contamination sources?
- **Validation of underlying flow physics**
- **Useful measures for good ventilation**
- **Some case studies**
  - Operating theatre
  - Community centre
  - Restroom
  - Canteen / restaurant
  - Assembly plant
  - Office (executive, open-plan, connected)
  - UK C-19 Mobile Testing Unit
  - Dental and Endoscopy treatment rooms with AGPs and fallow time

IsoSurface of Age of Air at 50 sec



What can we gain from CFD Simulation?

Air movement and Aerosol Transport

- Insights
  - Maximise fresh-air penetration and identify recirculation dead-spots
  - Understand where contamination sources could spread
  - Understand and use the concept of air-curtains
  - Design furniture placement and occupant placement to minimize transmission risk
  - Understand where particles deposit on surfaces

- Metrics
  - Age of the air (hrs/mins/sec) everywhere in the enclosure
  - Fresh Air Index (FAI) – a measure to compare the local air freshness versus the enclosure ventilation rating (air-changes per hour)
  - Contamination source index (CAI) – arising from super-spreaders coughing/breathing/talking
    - How CAI interacts with FAI
  - Air filtration/cleaning (UV/ionization/plasma) devices for efficient placement
    - Interaction with CAI
    - Interaction with surface contamination

What are the Underlying Flow Regimes?

Air movement and Aerosol Transport

- Fluid Dynamics
  - CFD (Computational Fluid Dynamics) solves the ***Navier-Stokes equations governing continuum fluid mechanics*** using a finite-volume approach and high-performance computing (HPC)
  - Turbulence
  - Buoyancy
  - Heat fluxes and Radiation
  - Transient Impulses (cough, breathing …)

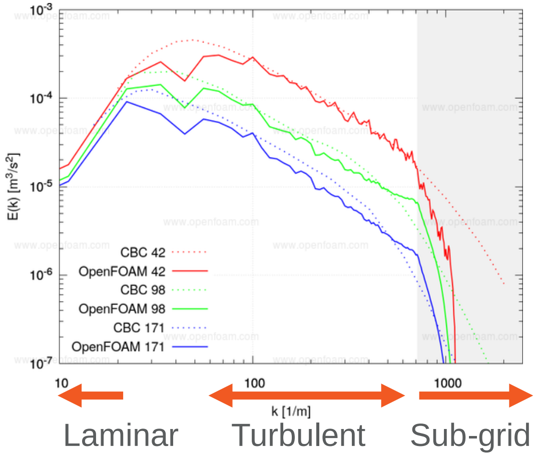
- Aerosols particulates
  - CFD (Computational Fluid Dynamics) additionally solves ***discrete particle mechanics fully coupled*** with the continuum fluid mechanics
  - Droplet size distribution (sub-micron up to two-orders larger)
  - Solid (pathogen) and liquid (water, fat, mucus) content
  - Heat transfer (including ultraviolet radiation) and mass transfer
  - Turbulence collision, break-up and dispersion

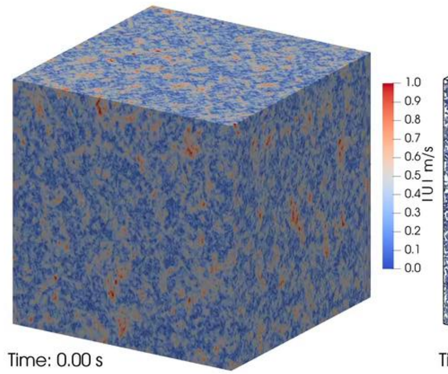
Underlying Flow Regimes: Fluid Dynamics

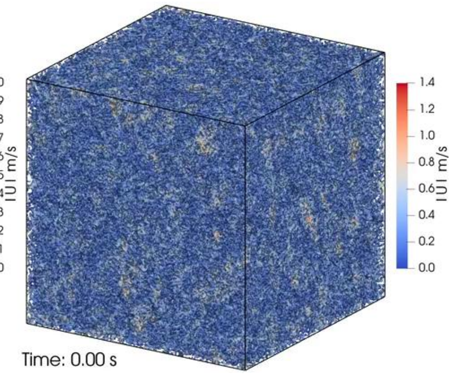
Turbulence

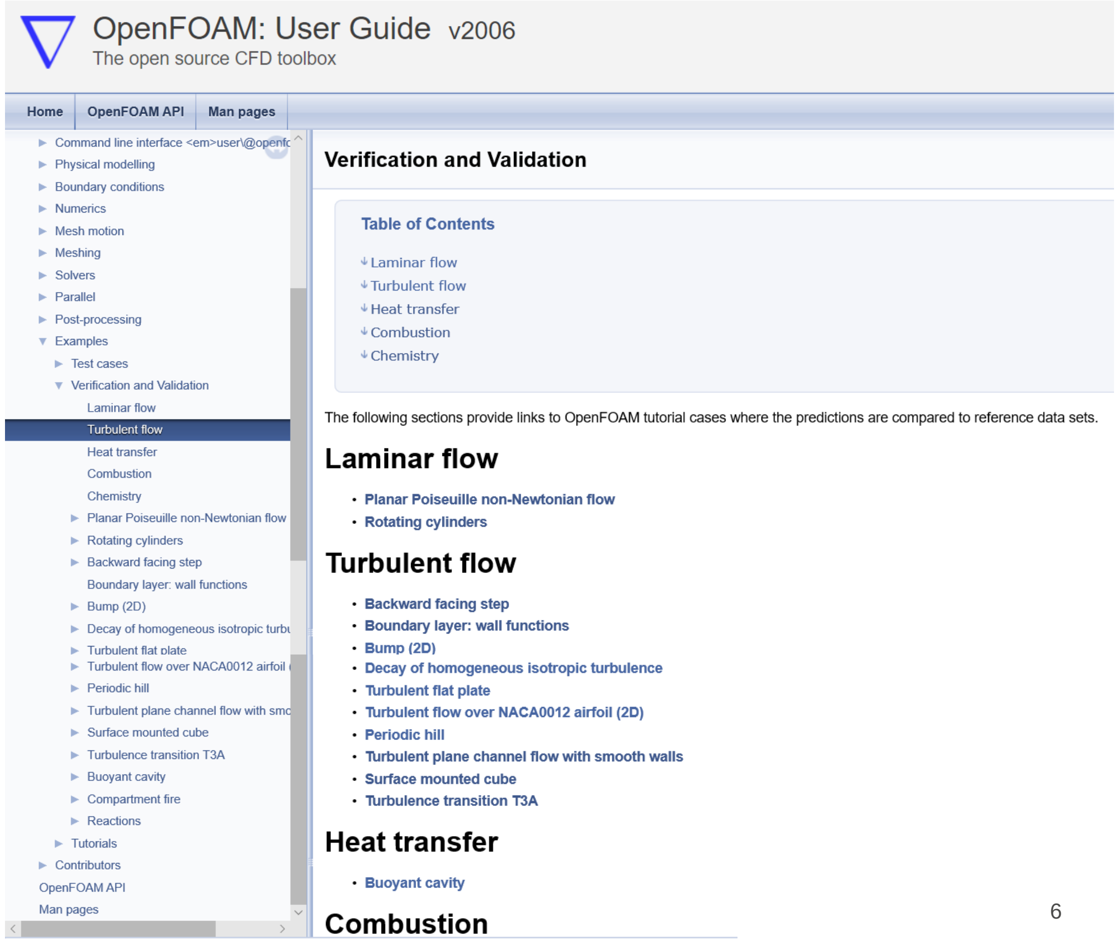
- Reynolds Number in the enclosure determines the turbulence regime
  - Turbulent, laminar, transitional

- OpenFOAM validations
  - RANS
  - LES-based





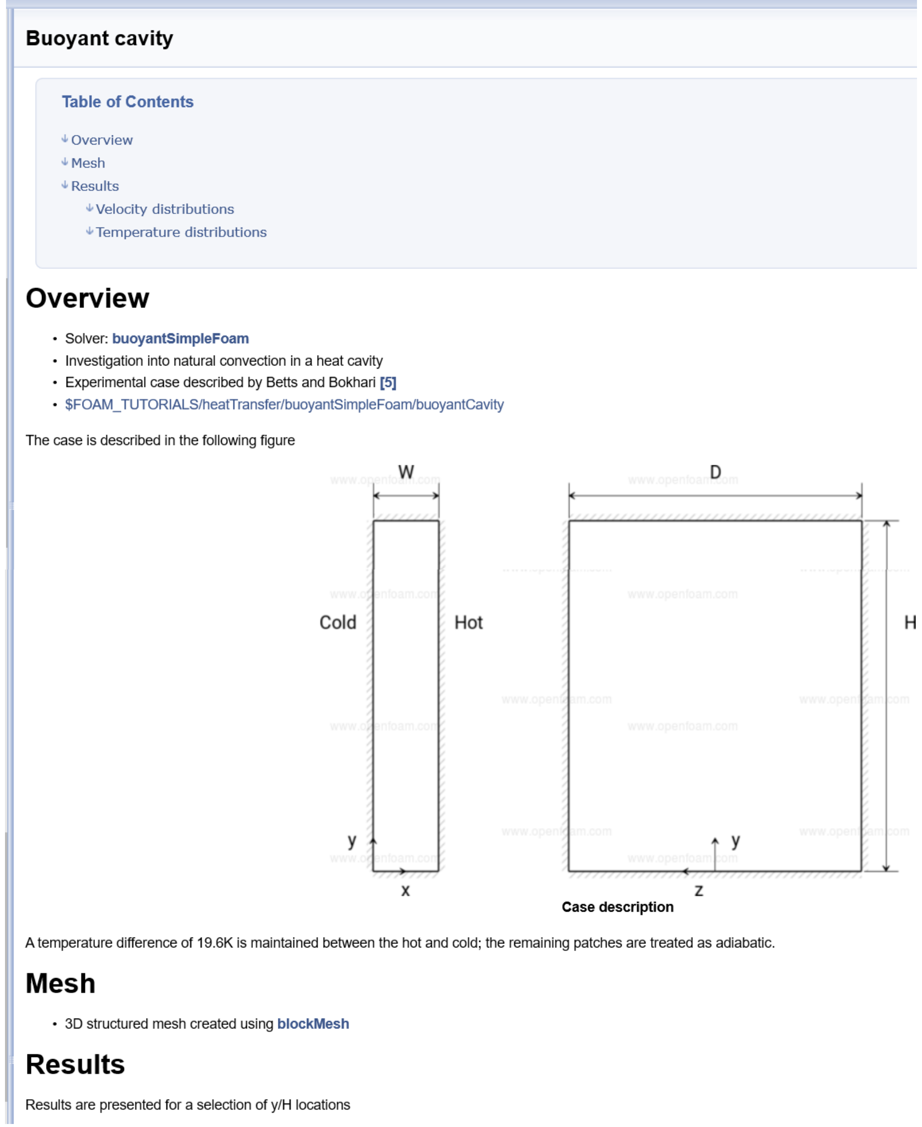




Underlying Flow Regimes: Fluid Dynamics

Buoyancy

- Laminar heated cavity
  - Wall heat flux
  - Buoyancy driven flow recirculation



Buoyant cavity

Table of Contents

- Overview
- Mesh
- Results
  - Velocity distributions
  - Temperature distributions

Overview

- Solver: buoyantSimpleFoam
- Investigation into natural convection in a heat cavity
- Experimental case described by Betts and Bokhari [5]
- $FOAM_TUTORIALS/heatTransfer/buoyantSimpleFoam/buoyantCavity

The case is described in the following figure

Case description

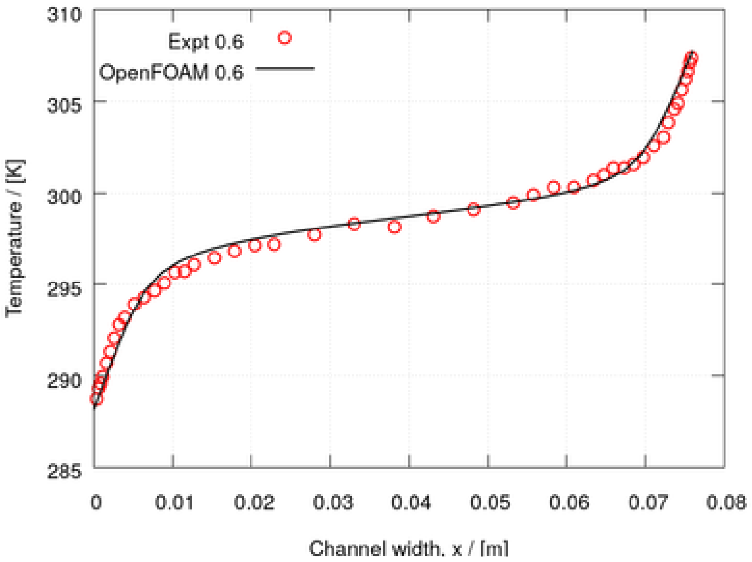
A temperature difference of 19.6K is maintained between the hot and cold; the remaining patches are treated as adiabatic.

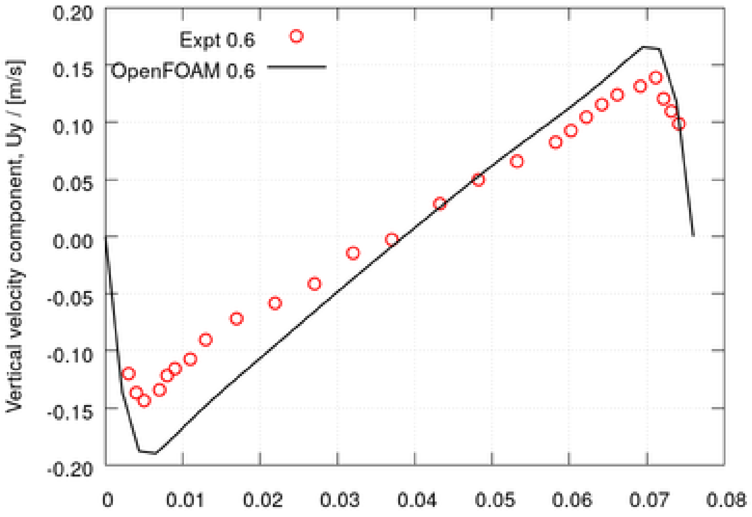
Mesh

- 3D structured mesh created using blockMesh

Results

Results are presented for a selection of y/H locations

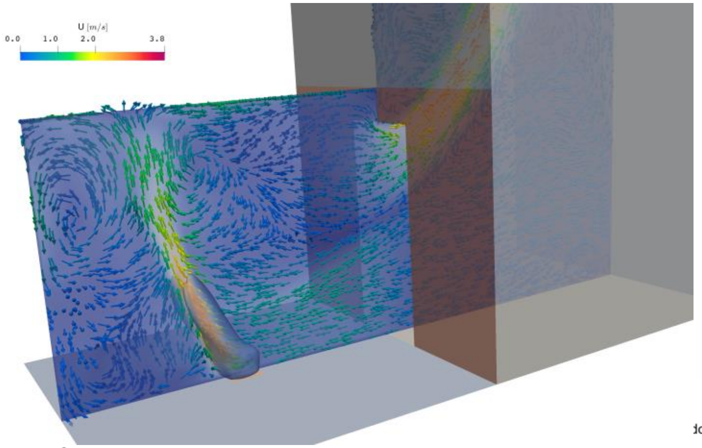


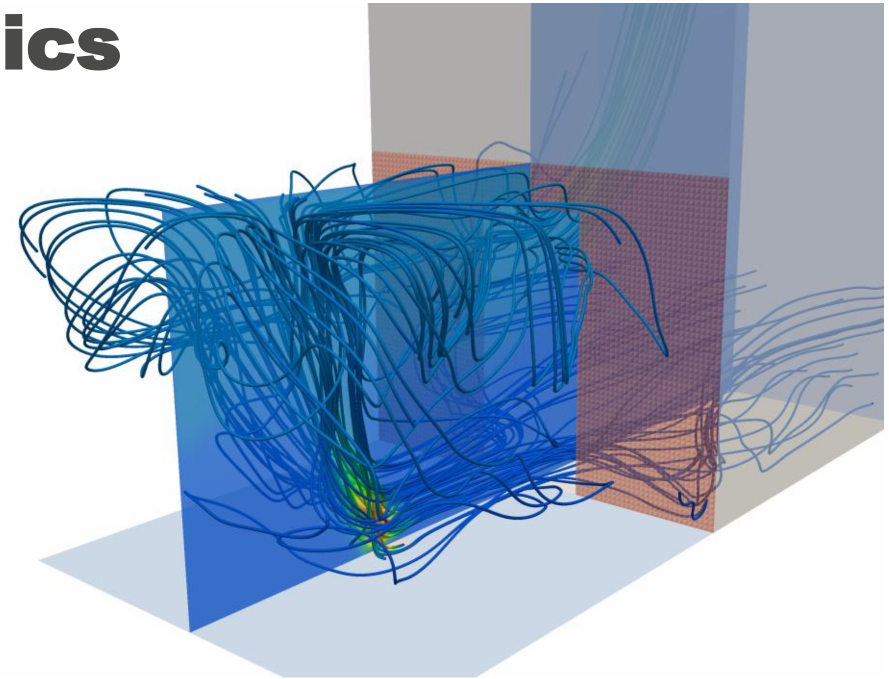


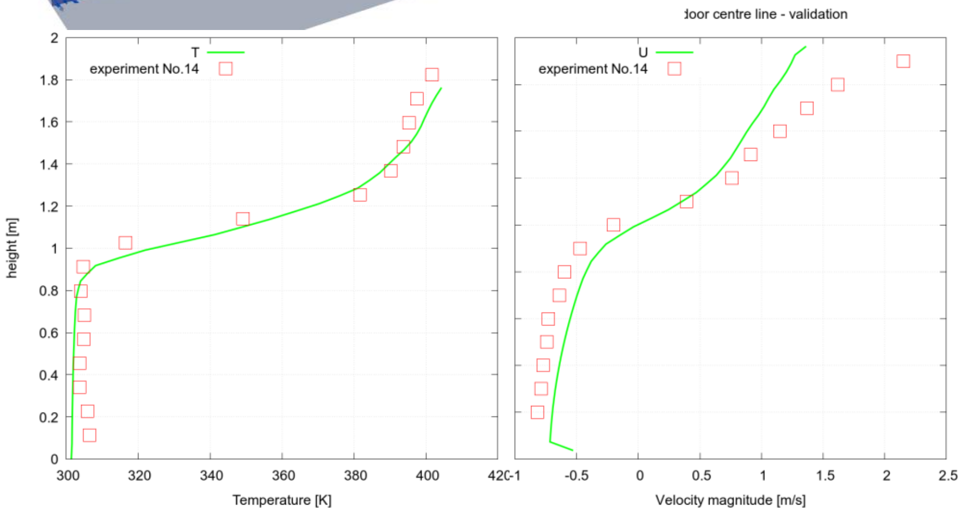
Underlying Flow Regimes: Fluid Dynamics

Heat flux and Radiation

- Steckler thermally stratified enclosure
    - Volume heat source
    - Wall heat transfer
    - Enclosure radiation exchange
    - Open door inflow/outflow
  - Thermally stratified flow
  - Outflow at the top of the door
  - Inflow through the bottom
  - Measurement stack along door centerline
    - Validated temperature profile
    - Validated velocity profile

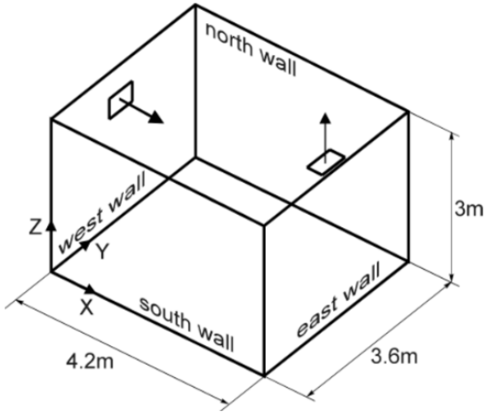






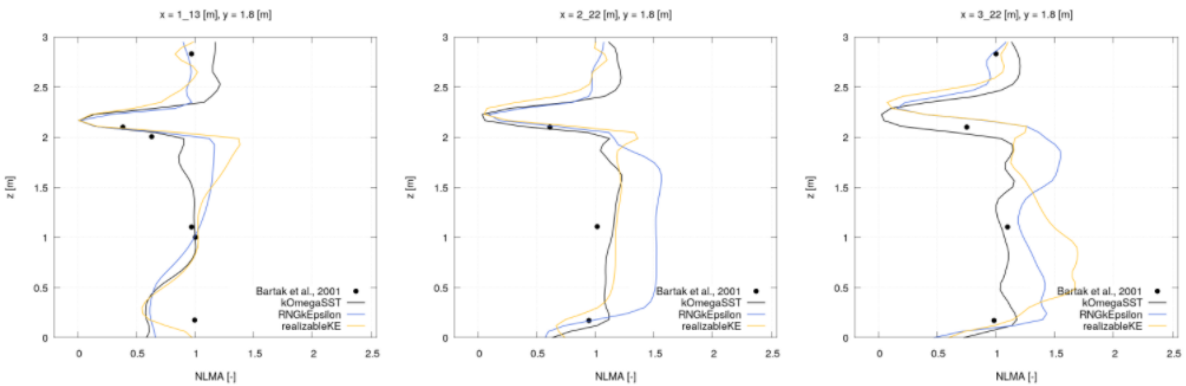
Underlying Flow Regimes: Fluid Dynamics

Age of Air (AoA)

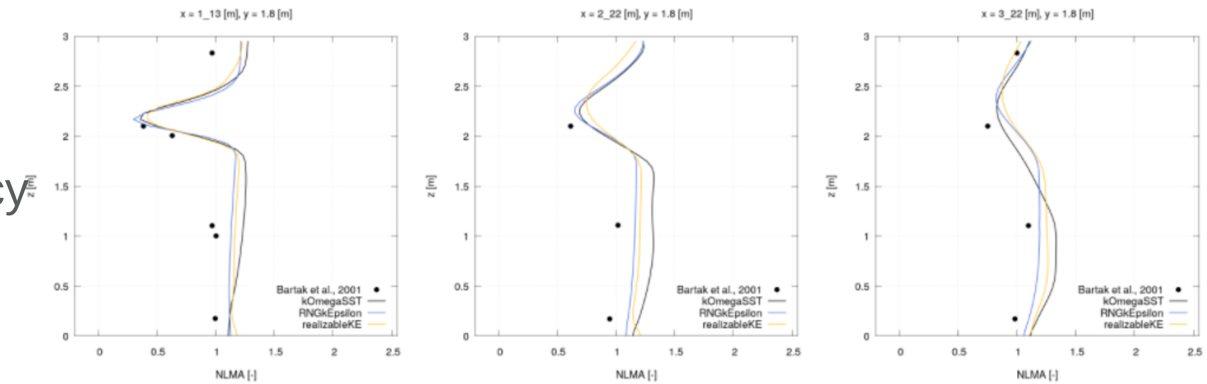


- Spread of “fresh” uncontaminated air from an external source
    - Open doors or windows
    - External source through Aircon or Heater
    - Air filtration units
- Passive scalar AoA (sec) solved
    - Turbulence diffusion “off” so as to maximise the convective transport physics
        - OpenFOAM test-repository
- Turbulence model effects are marginal
    - k-ω-SST vs. RNG vs. Realisable_k-ε
    - **k-ω-SST** selected for steady/DES consistency

Case: scalarTransport, alphaD=1, alphaDt=0, nCorr=0



Case: scalarTransport, alphaD=0, alphaDt=1, nCorr=0



Underlying Flow Regimes: Fluid Dynamics

Transient impulses (reduced to mean effect?)

- Respiration impulses; verifying qualitative patterns; cycles/persons are not repeatable …
  - Spread angle and Penetration
    - Coughing (see far right >)
    - Breathing with and w/o mask (see images left)
    - Talking (see images below right)

Fundamental protective mechanisms of face masks against droplet infections

Christian J. Kähler (Prof. Dr.) and Rainer Hain (Dr.)

Institute of Fluid Mechanics and Aerodynamics, University of the Bundeswehr Munich, Werner-Heisenberg-Weg 39, 85577 Neubiberg, Germany

Corresponding author: christian.kaehler@unibw.de

Characterizing exhaled airflow from breathing and talking

Abstract The exhaled air of infected humans is one of the prime sources of contagious viruses. The exhaled air comes from respiratory events such as the coughing, sneezing, breathing and talking. Accurate information on the thermo-fluid characteristics of the exhaled airflow can be important for prediction of infectious disease transmission. The present study developed a source model to provide the thermo-fluid conditions of the exhaled air from the breathing and talking processes. The source model is a set of equations obtained from the measurements of the flow rate, flow direction, and area of mouth/nose opening

Jitendra K. Gupta[1], Chao-Hsin Lin[2], Qingyan Chen[1]

[1]National Air Transportation Center of Excellence for Research in the Intermodal Transport Environment (RITE), School of Mechanical Engineering, Purdue University, West Lafayette, IN, USA, [2]Environmental Control Systems, Boeing Commercial Airplanes, Everett,

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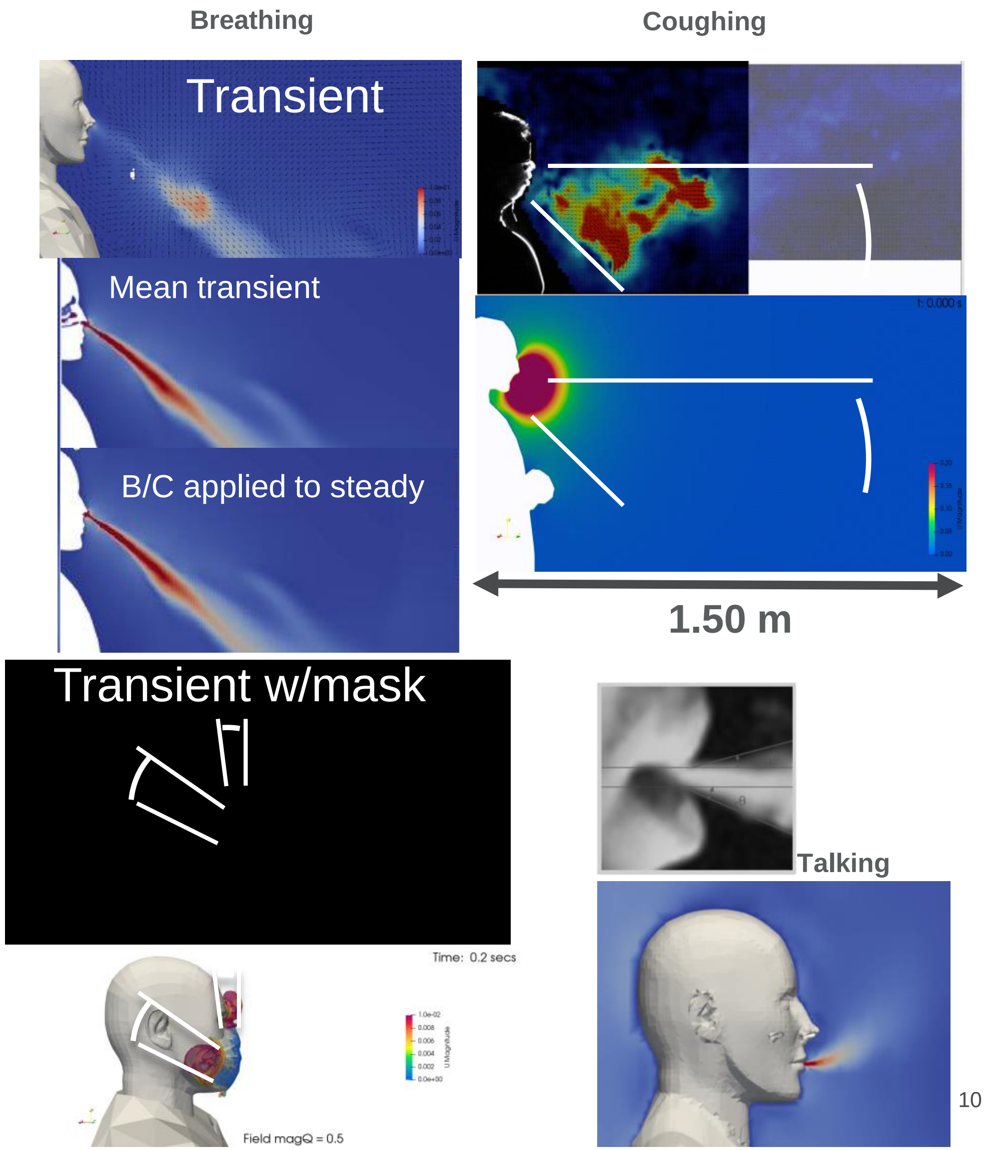
doi:10.1111/j.1600-0668.2009.00623.x



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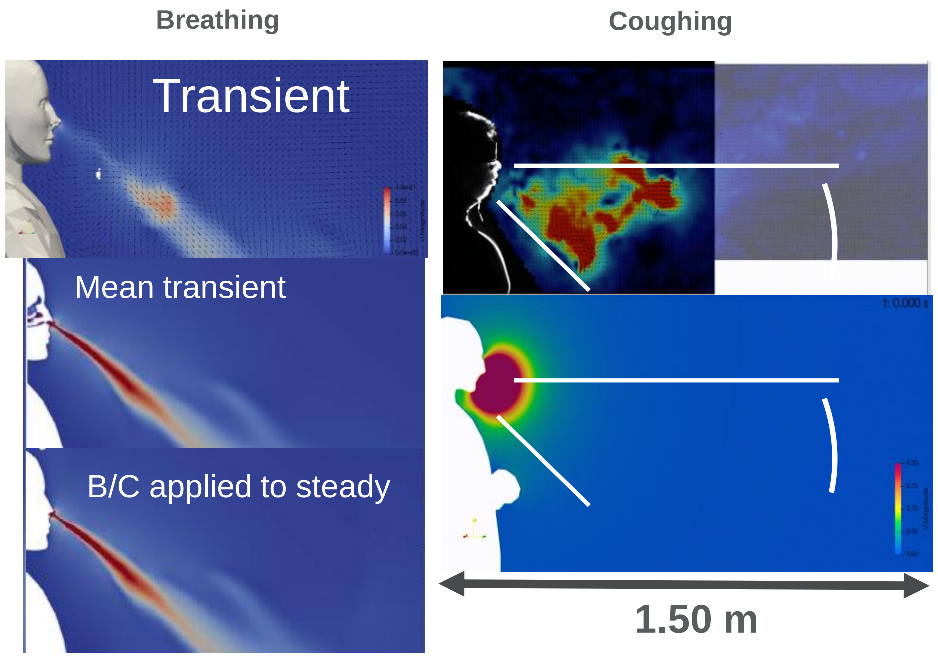

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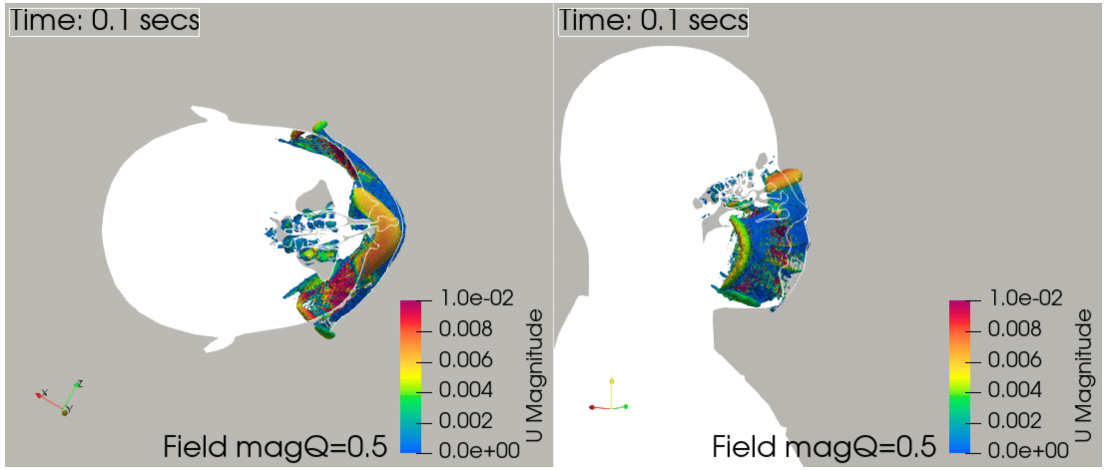


Underlying Flow Regimes: Fluid Dynamics

Metrics

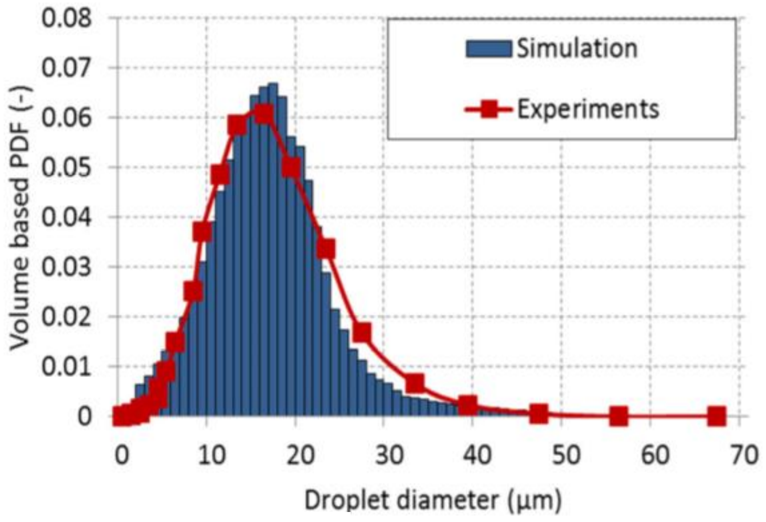
- “**Air Changes per Hour**” (ACpH) and “**Age of Air**” (AoA)
  - “Air changes per hour” ACpH
    - Time for one-exchange = Volume (m^3) / Volume flow rate (m^3 /hr)
    - ACpH = 1 hr / (Time for one exchange)
  - How long has the air “actually” been in the room?
    - Driven by
      - Convection
      - Diffusion
      - Recirculation
    - AoA steady-state solution unique our implementation in OpenFOAM

- **Fresh Air Index (FAI)** = AoA * ACpH
  - Normalised measure from steady-state
    - = 1 … Neutral rating
    - < 1 … Air is “fresh”
    - > 1 … air is “stale”

Underlying Flow Regimes: Aerosols

Droplet size distribution

- Particle trajectories
  - ILASS validation paper (2016)
  - Sprays with wide range of particle sizes
    - Particle interaction, collision, breakup and coalescence
    - Air jet and spray penetration



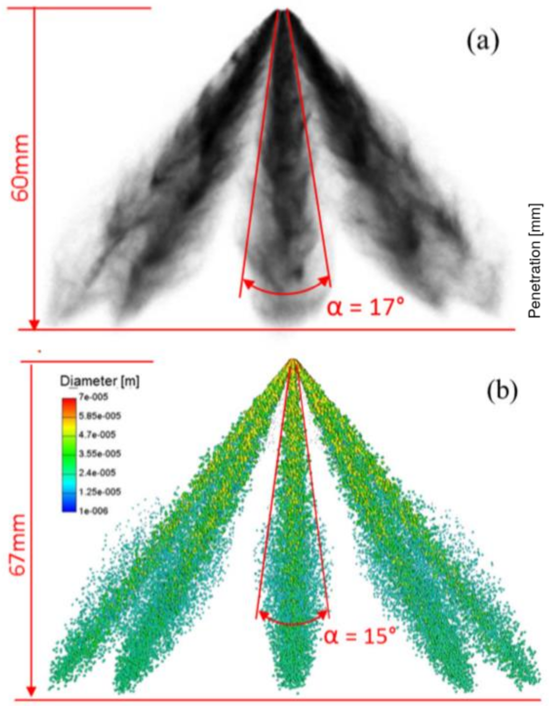
ILASS Americas 28th Annual Conference on Liquid Atomization and Spray Systems, Dearborn, MI, May 2016

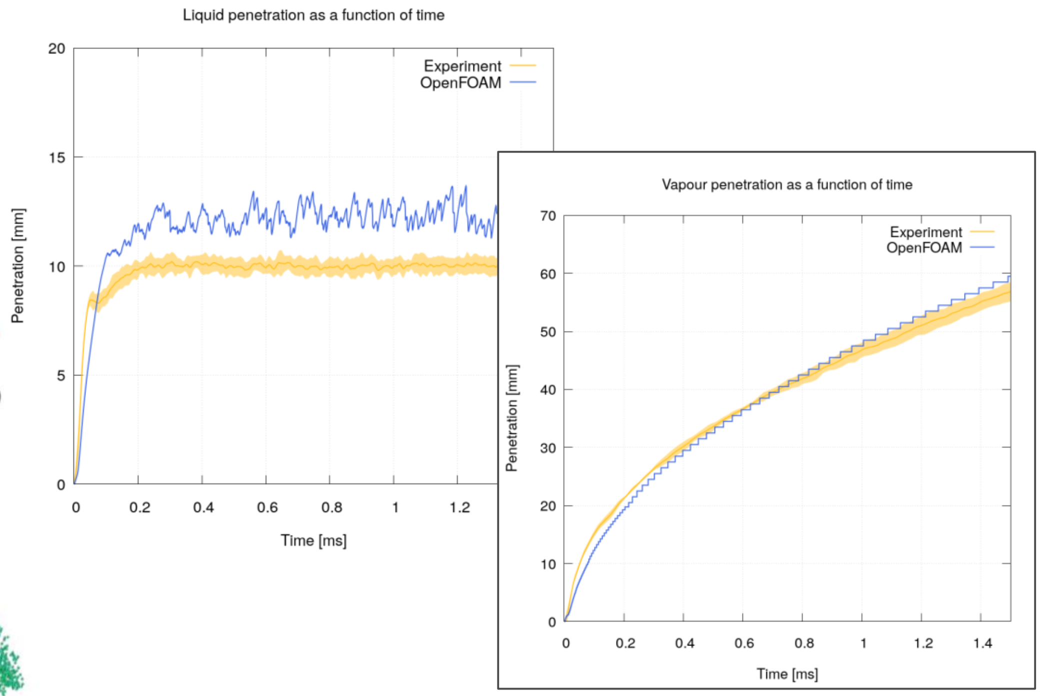
ECN GDi Spray G: Coupled LES Jet Primary Breakup - Lagrangian Spray Simulation and Comparison with Data

B. Befrui*[,1], A. Aye[1], A. Bossi[1], L. E. Markle[2] and D. L. Varble[2]
[1] Delphi Customer Technology Center, Bascharage, G.-D. Luxembourg
[2] Delphi Technical Center Rochester, Henrietta, USA

Abstract
Computational fluid dynamic (CFD) simulation of in-cylinder mixture preparation is an important component of the gasoline direct injection (GDi) engine spray pattern (or targeting) optimization process. A major area of shortcoming in CFD Lagrangian stochastic simulation of GDi spray is the proper account of the jet primary breakup (with regards to the initial droplet size - velocity distribution function) due to the substantial influence of nozzle geometry on the primary atomization process. The objective of this study is to assess the predictive capability of the volume-of-fluid large-eddy-simulation (VOF-LES) method for quantitative analysis of the spray primary breakup, so to enable a fully predictive analysis of the complete GDi spray processes. The paper presents results from a VOF-LES analysis of the ECN spray G seat flow and the near-field primary atomization coupled to a Lagrangian stochastics simulation method adopting the discrete droplet model (DDM). The analysis is carried out for a vaporizing n-Heptane spray injection into the atmospheric ambient. The distinction of this case, compared with previous application of the method, is the notable interaction of spray with the counter-bore walls. Hence, the interest is whether the VOF-LES method properly captures the interaction effects on the spray plume primary atomization.

The injector internal flow and jet primary breakup simulation is performed with the Open-FOAM software suite. The simulation of the spray processes - propagation, secondary atomization, and the droplet-air exchanges - are carried out using the AVL-FIRE commercial CFD code. The accuracy of the VOF-LES primary atomization data is inferred from the predictive accuracy of the simulated far-field spray plume trajectory, cone angle, droplet-size

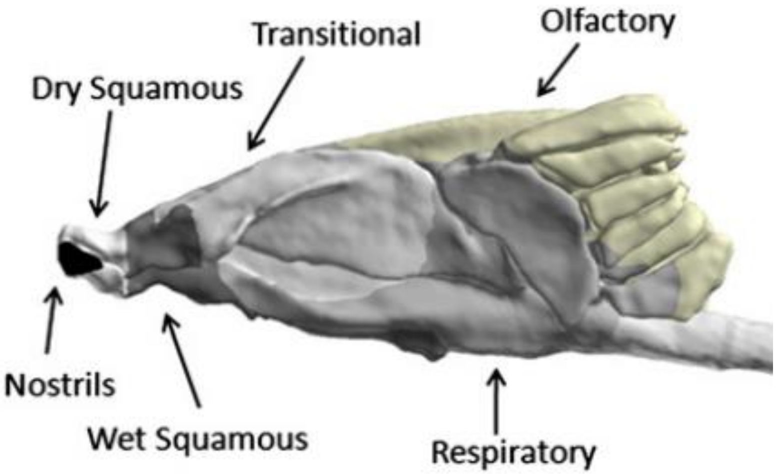




Underlying Flow Regimes: Aerosols

Aerosol penetration

- Penetration in nasal passages
- Sub-micron and micrometer particle deposition
- Joint investigation with PNNL
    - Presented at the 2017 OpenFOAM Conference



Computational fluid dynamics simulations of submicrometer and micrometer particle deposition in the nasal passages of a Sprague-Dawley rat

January 2012 · Journal of Aerosol Science 43(1):31-44
DOI: 10.1016/j.jaerosci.2011.08.008

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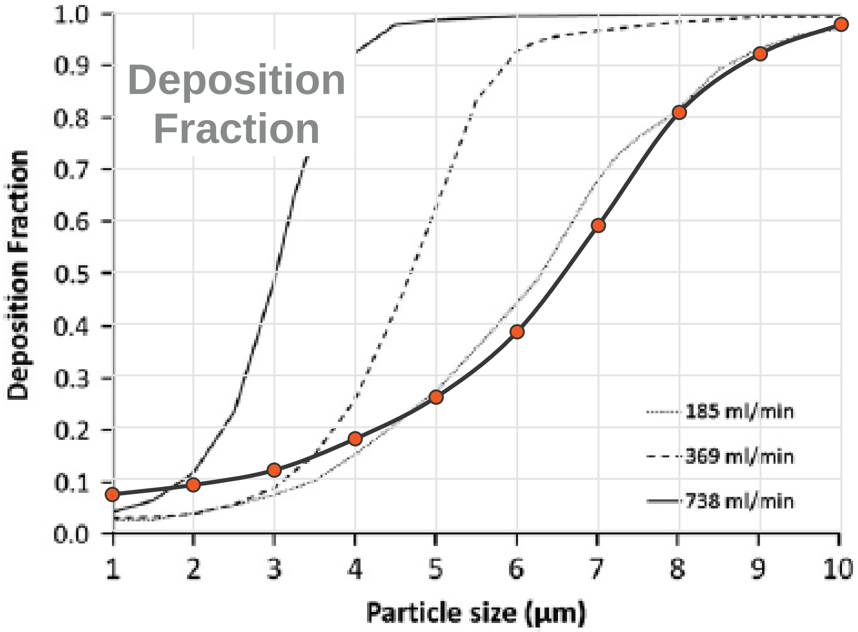
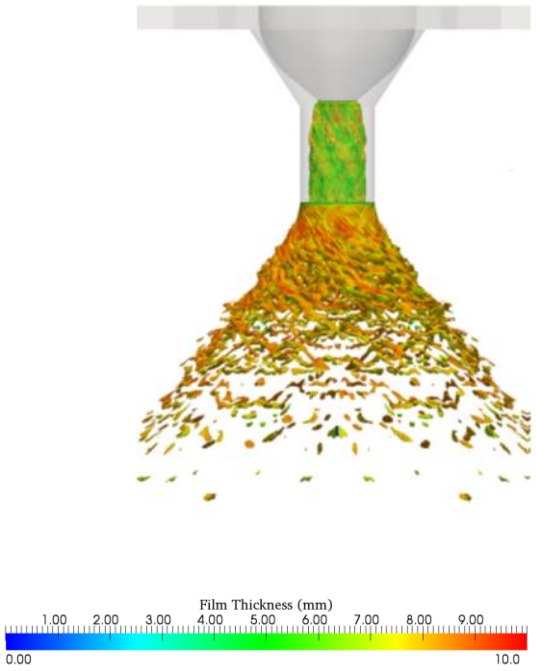
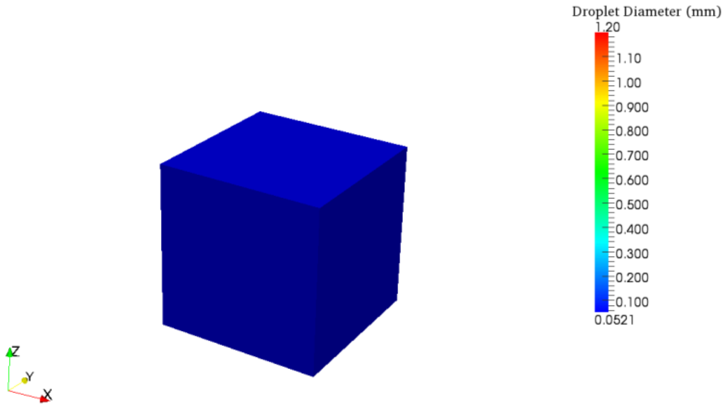


Underlying Flow Regimes: Aerosols

Aerosol, flow and heat transfer interaction

- Common in ICE and Coal fired power for which OpenFOAM has been extensively deployed
- Aerosol spray atomisation models
  - hollow/solid cone injectors, injector arrays,
  - Sauter-mean diameter/velocity/trajectory droplet distribution
- Aerosol atomisation prediction
  - VoF modelling of liquid paint injection
  - LES simulation of primary atomization of liquid paint into droplets
- Aerosol-surface interactions
  - WeberNumber-based droplet/surface interaction
    - bounce,
    - shatter
    - Stick
    - film-formation
  - Transport of resulting surface liquid film
  - Full heat and mass (species) transfer with particles and surface film





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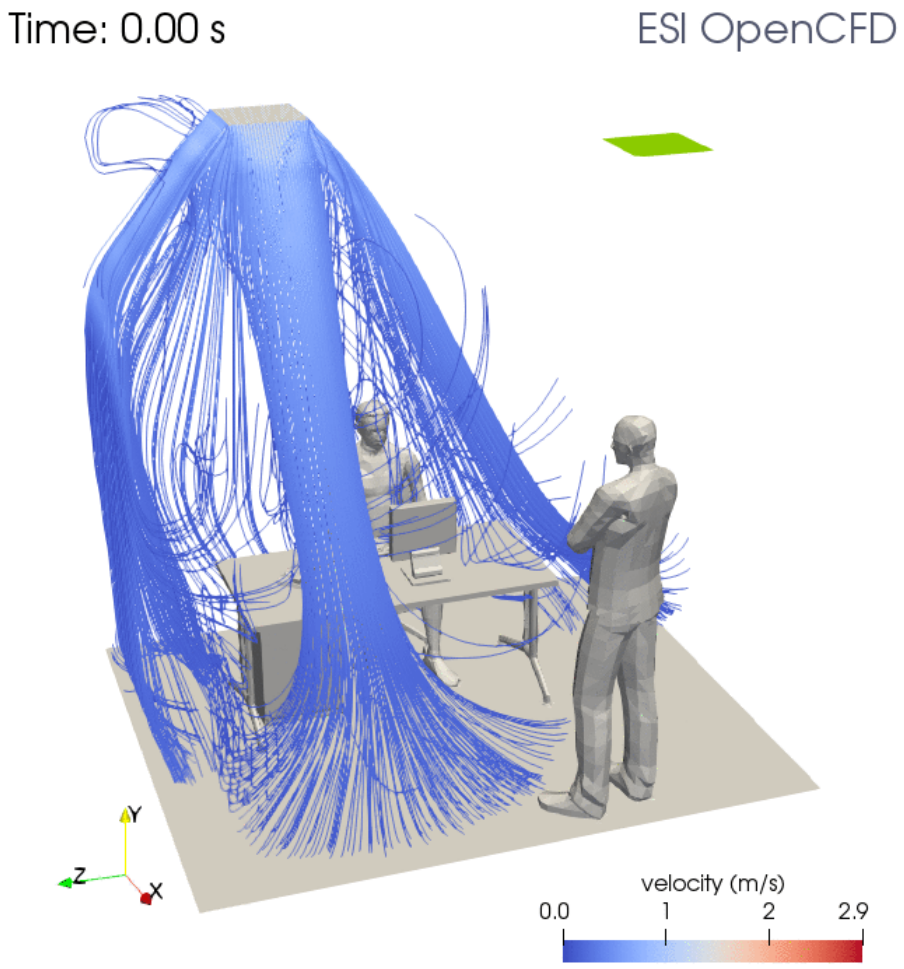
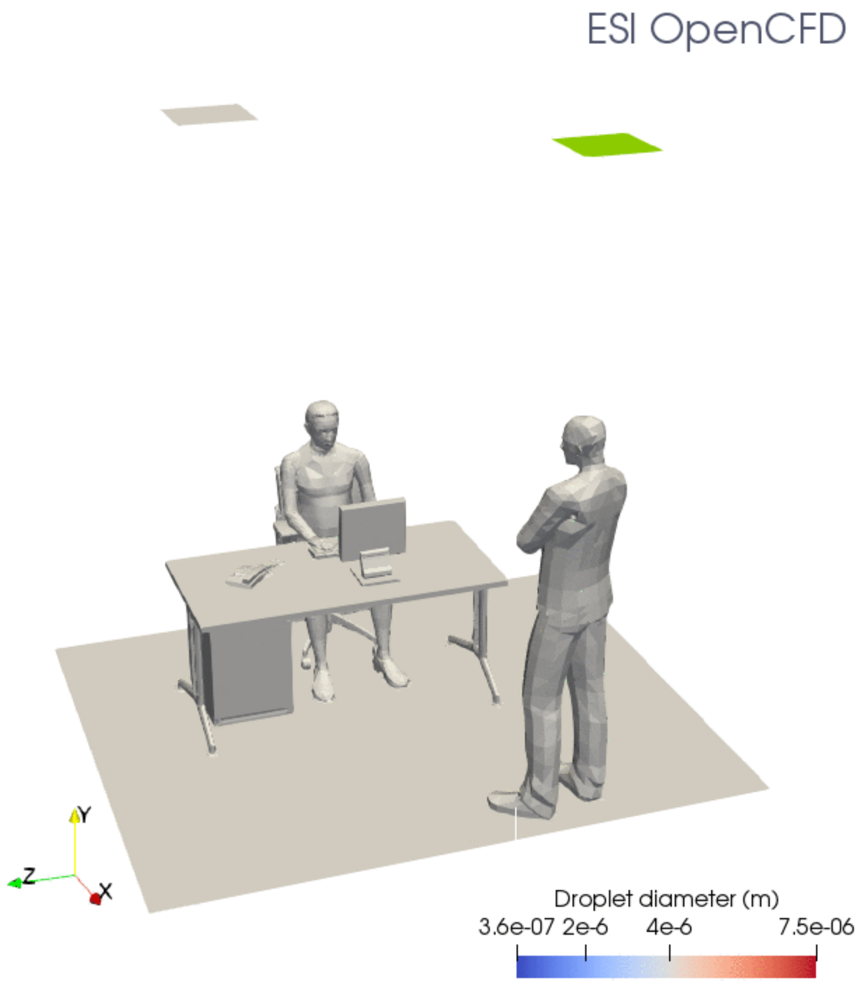
Underlying Flow Regimes: Summary

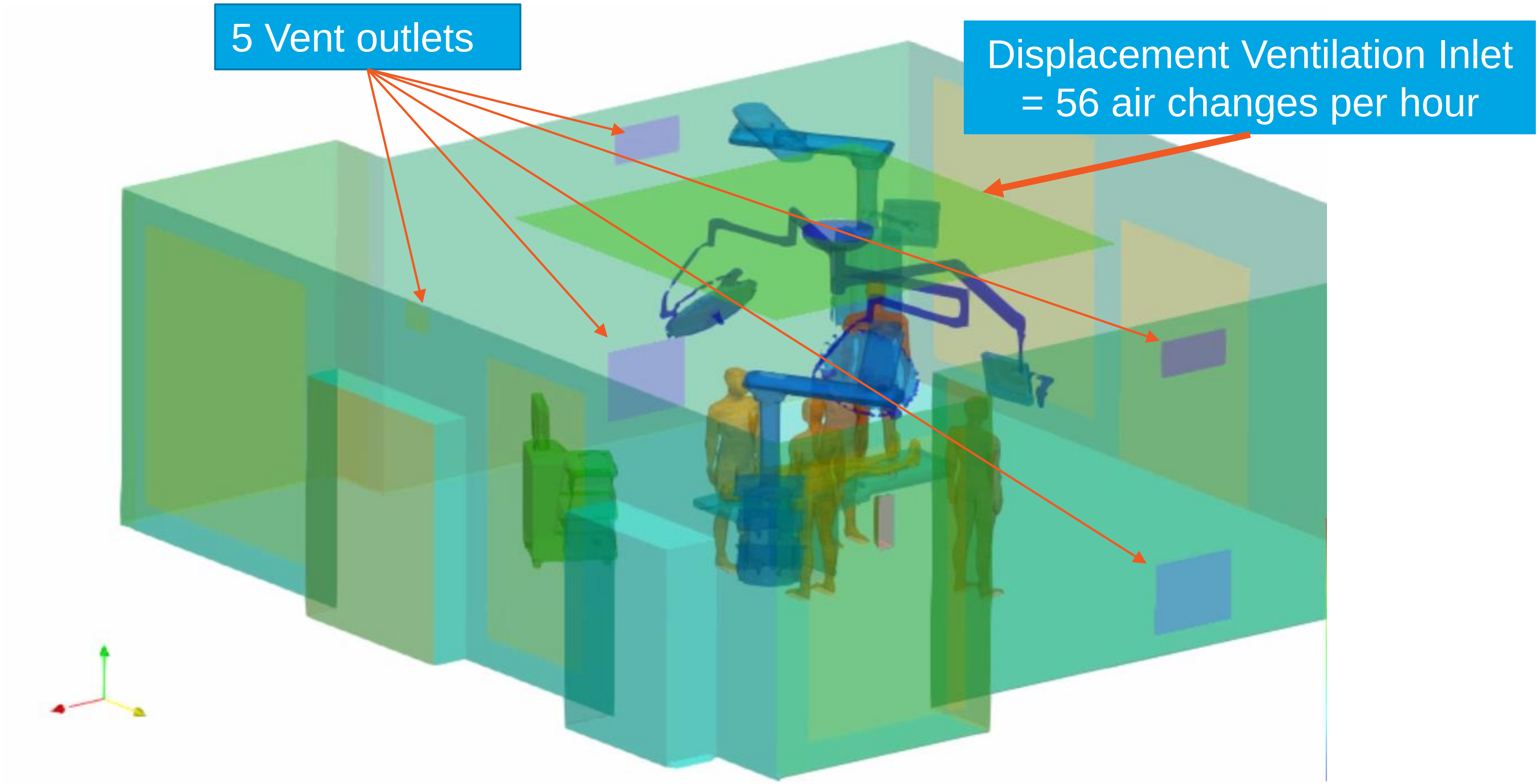
Aerosol and Flow; all physics combined





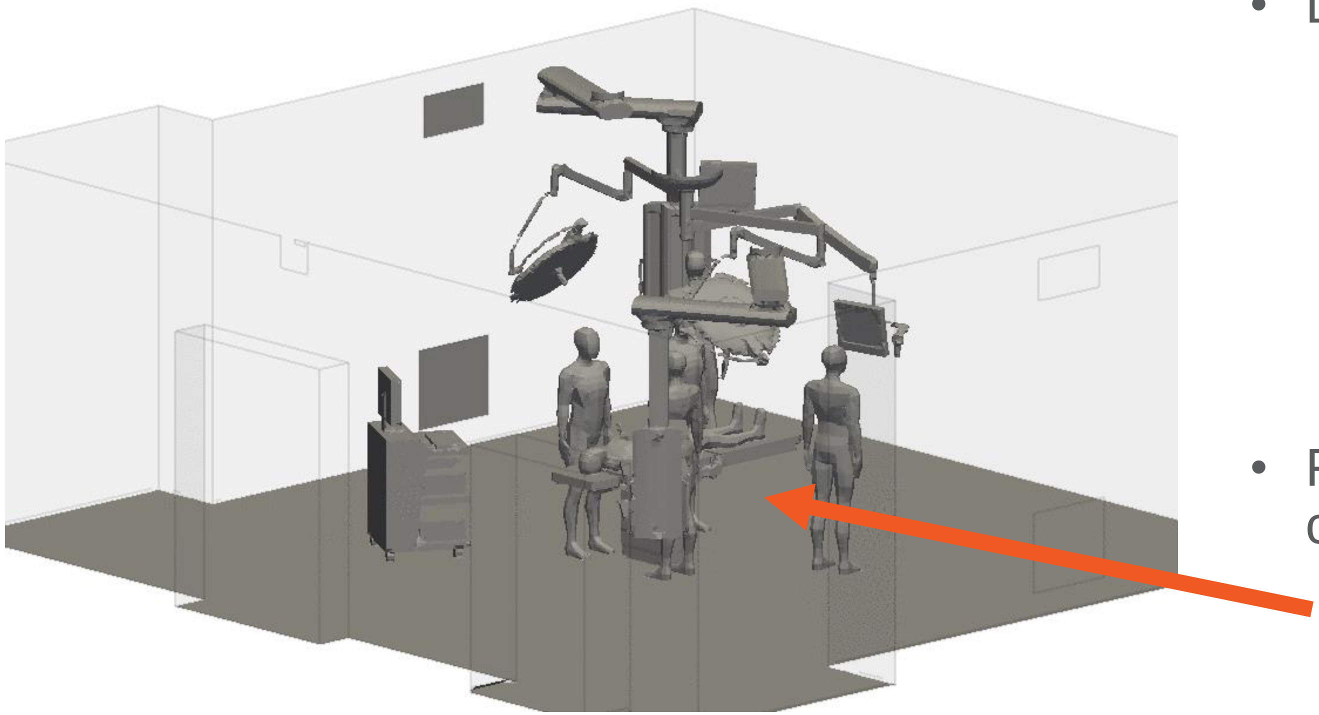
Operating Theatre Demonstrator

Layout: Theatre, staff, equipment, furniture and ventilation



Operating Theatre Demonstrator

Standard layout – results of CFD Fresh Air Index (FAI)



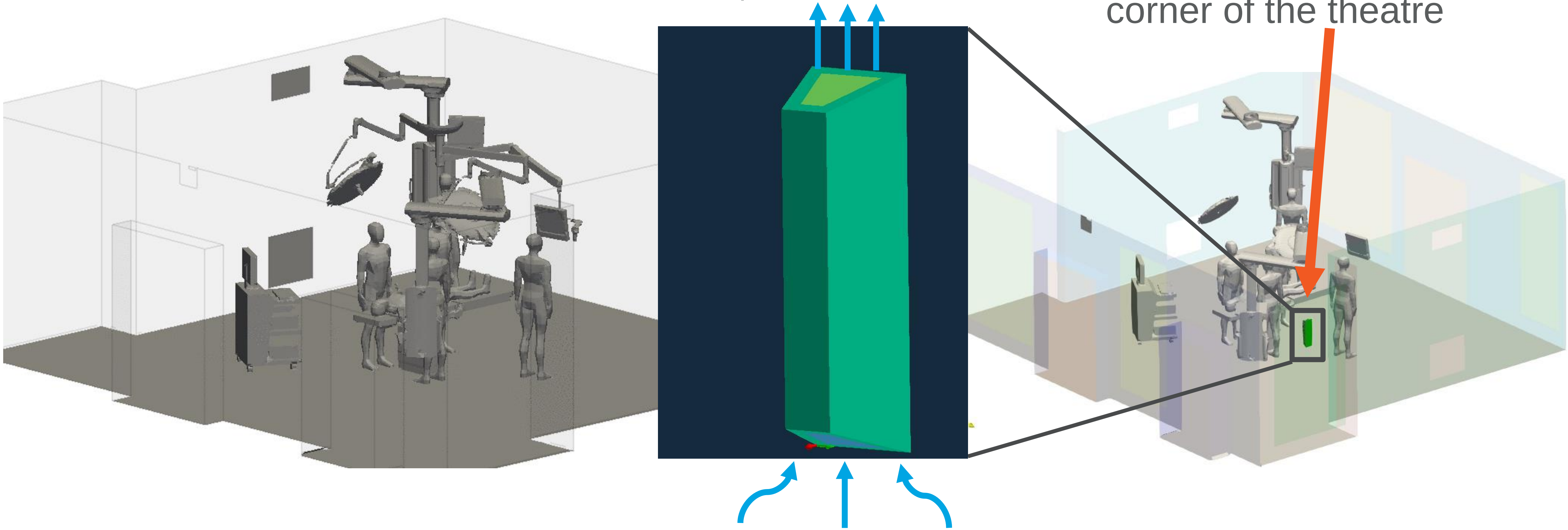
- Design details:
  - Inflow rate = 2.4 m^3/s
  - Volume = 154 m^3
  - Design air changes per hr = 56 (one airchange every 64sec)

- FAI indicates stale air locations in the room corners (red parts in the section-sweeps)
  - This would be a good corner location for a UV-filter / superoxide-plasma device

Operating Theatre Demonstrator

Modifying the layout – with filter device (single or dual purpose)

- UV-filter / superoxide-plasma device placed in the corner of the theatre

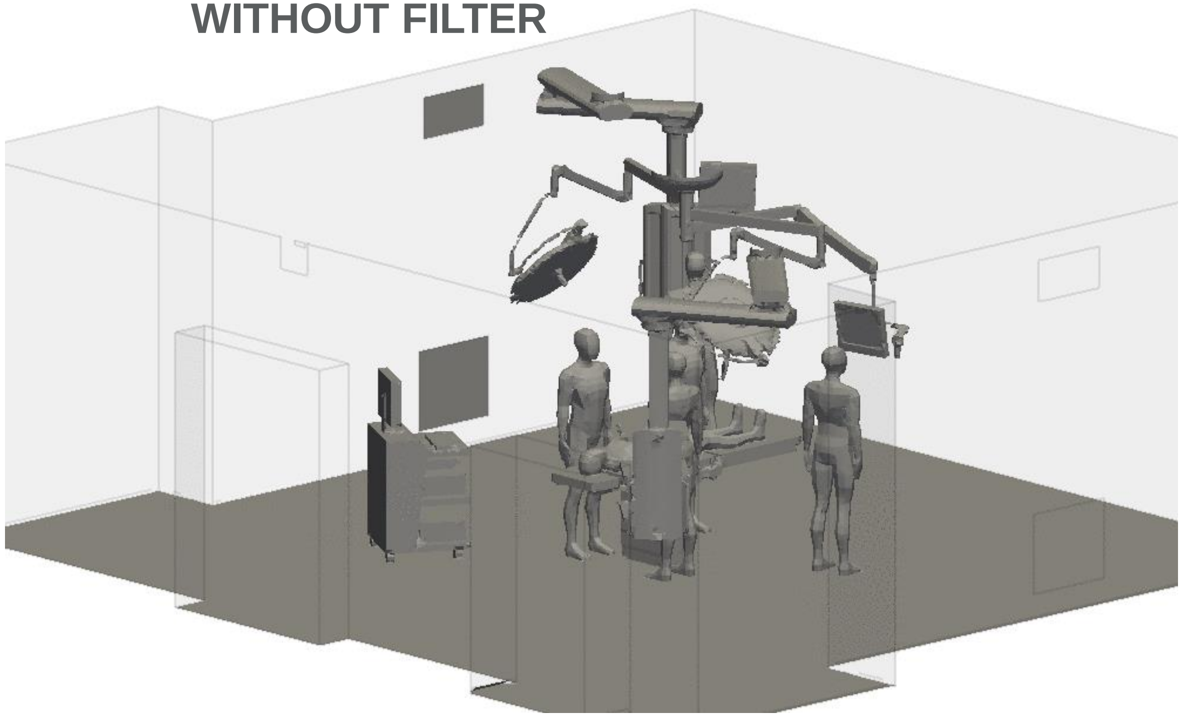


Operating Theatre Demonstrator

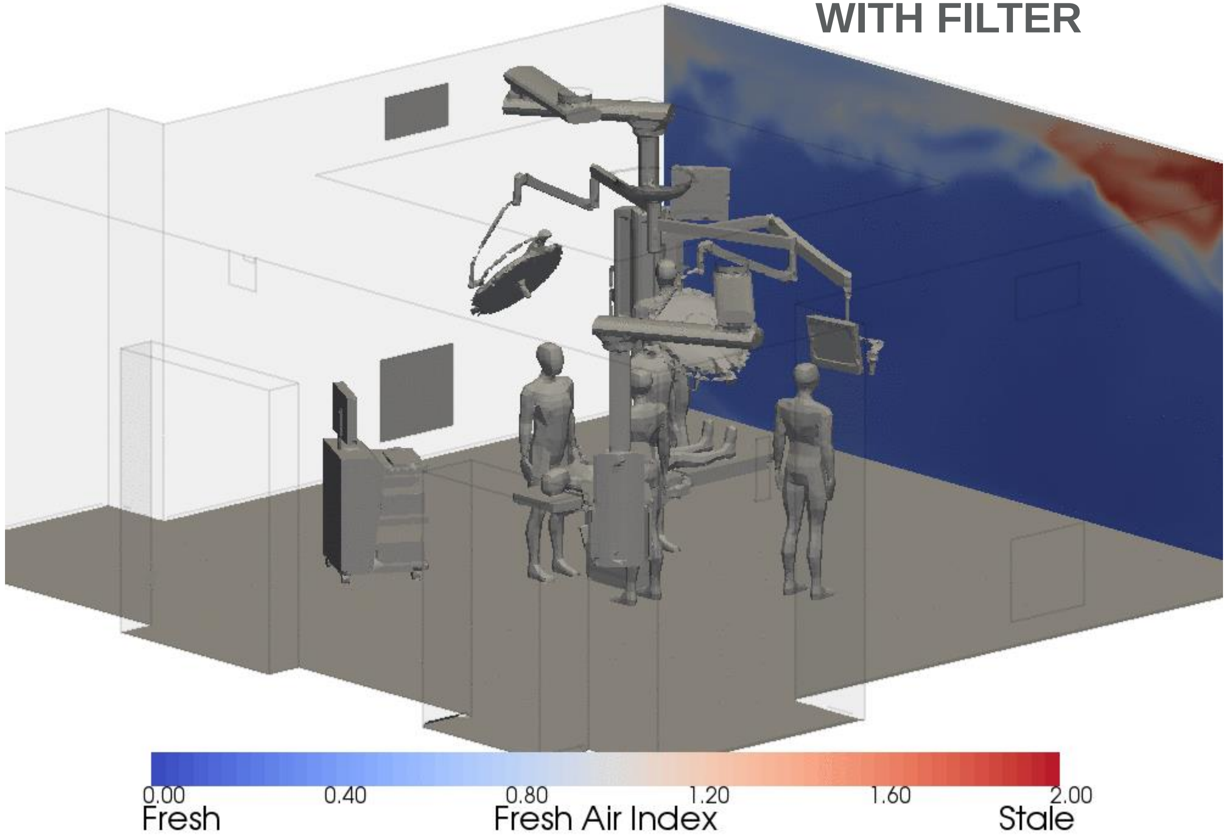
Standard versus Modified layout – with filter device

Plane at x = 3.746 m

WITHOUT FILTER



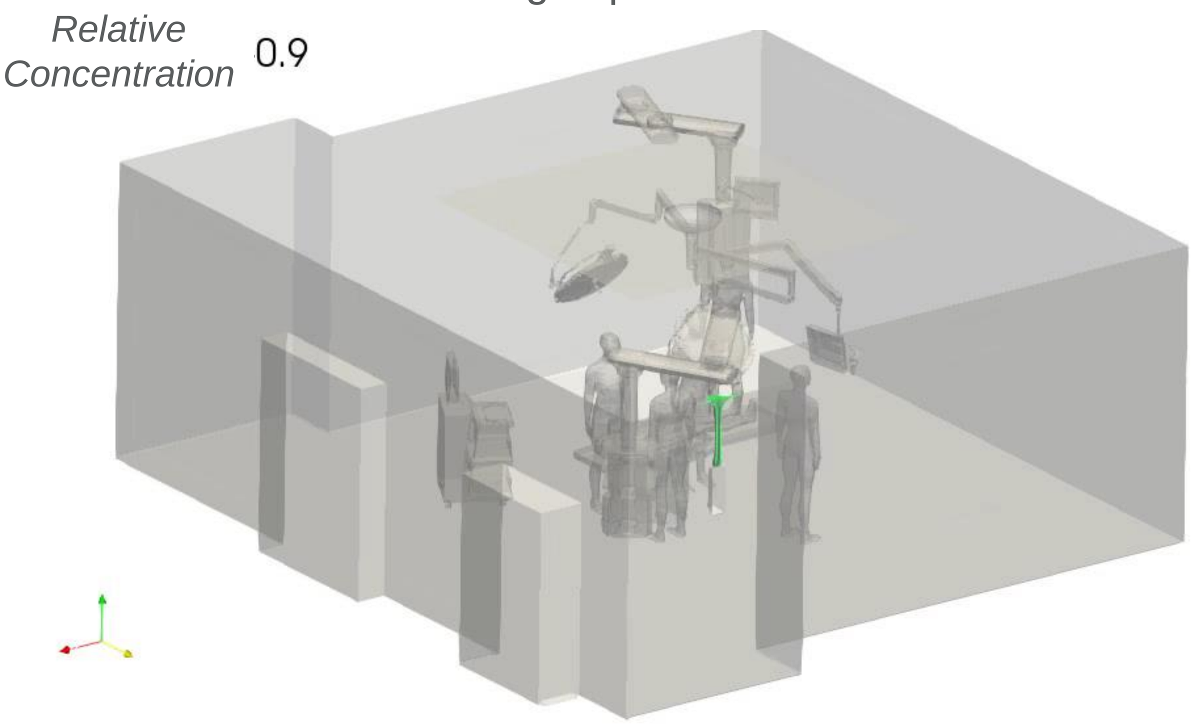
WITH FILTER

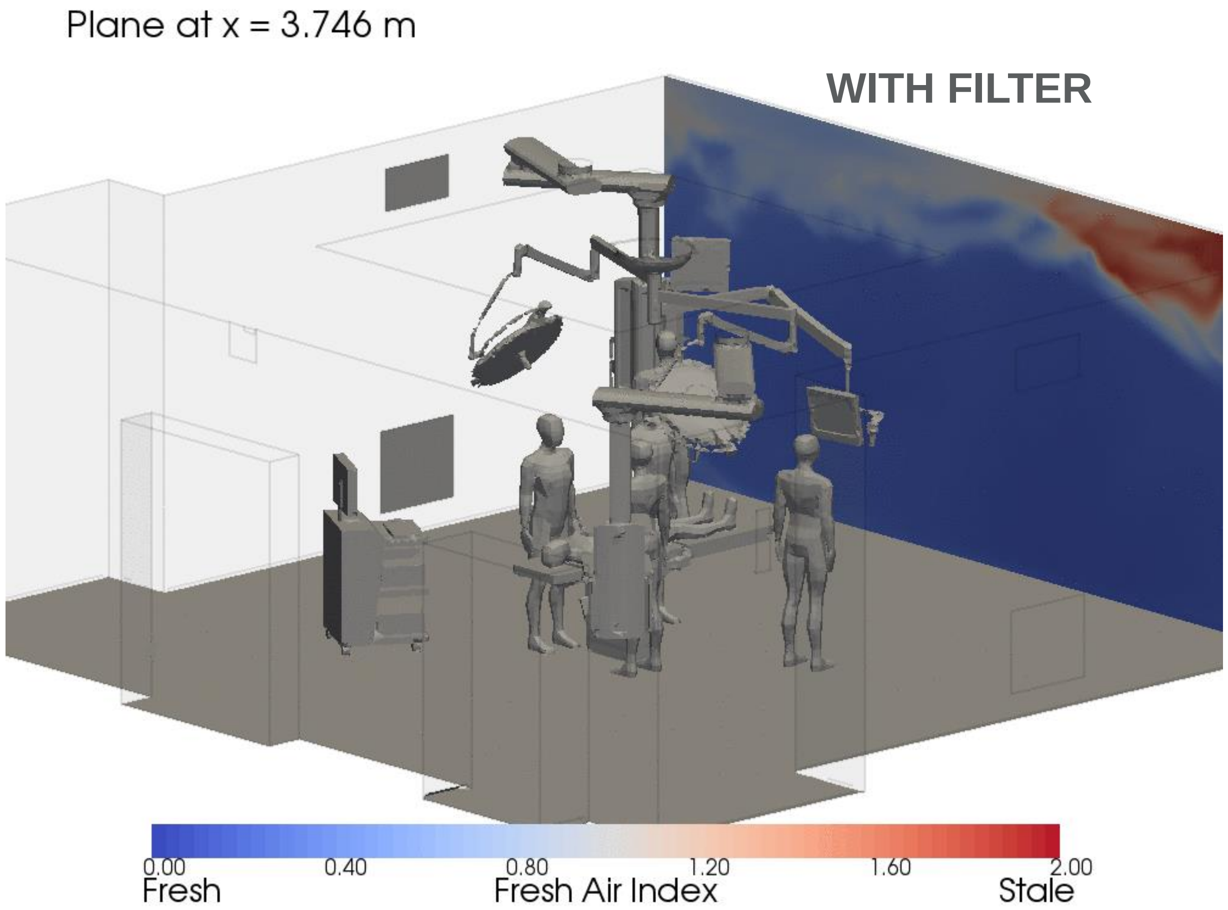


Operating Theatre Demonstrator

Modified layout – with filter device (dual purpose)

- Tracer plume (relative concentration) emitted from UV/ion-plasma device
    - Assumed passive, same properties as air
    - No further gas-phase reactions





COVID-19 Mobile Processing Units (MPU) Commissioning


OFFICIAL – COMMERCIAL

Department of Health & Social Care

Interim Engineering Evaluation of a Mobile Processing Unit (MPU) using Loop-Mediated Isothermal Amplification (LAMP) Technology

By

Captain G M McKenna REME

Lieutenant I R Campbell REME

A technical engineering evaluation report to support the engineering design of a Mobile Processing unit (Van) (MPU(V)).

British Army

Royal Electrical and Mechanical Engineers

Department for Health and Social Care

23 December 2020

OFFICIAL – COMMERCIAL

Rapid Testing Mobile Processing Units, Van(V) and Trailer(T)

Department of Health & Social Care

Funding body: Innovate UK
Project Title: Opensource software simulations towards understanding, monitoring and controlling COVID-19 transmission by managing air, people distancing and adapting urban environments
Project number: 85435
Funding Competition: UKRI Ideas to address COVID-19 – Innovate UK de minimis Aug 2020

Jan21-Feb21

Mobile Processing Units Commissioning

Using CFD to de-risk concerns

- Objectives:
    - **Occupancy health and safety** – guarantee a supply and circulation of fresh air
    - **Equipment maintenance** – ensure that equipment can be operated under the manufacturers specification
    - **Inform decision making** as to the efficient placement of ventilation/heating/aircon, **written into SOP**
- Commissioning:
    - **VAN**: 35 units designed, commissioned, fitted and operating Jan-Feb 2021
    - **TRAILER**: 30 units designed, commissioned, fitted and operating Feb-Mar 2021
- Stakeholders:
    - UK Government Department of Health and Social Care
    - Ministry of Defence deployment team
    - Chief Scientific Officer, NHS team
    - UK Public benefit

Department of Health & Social Care

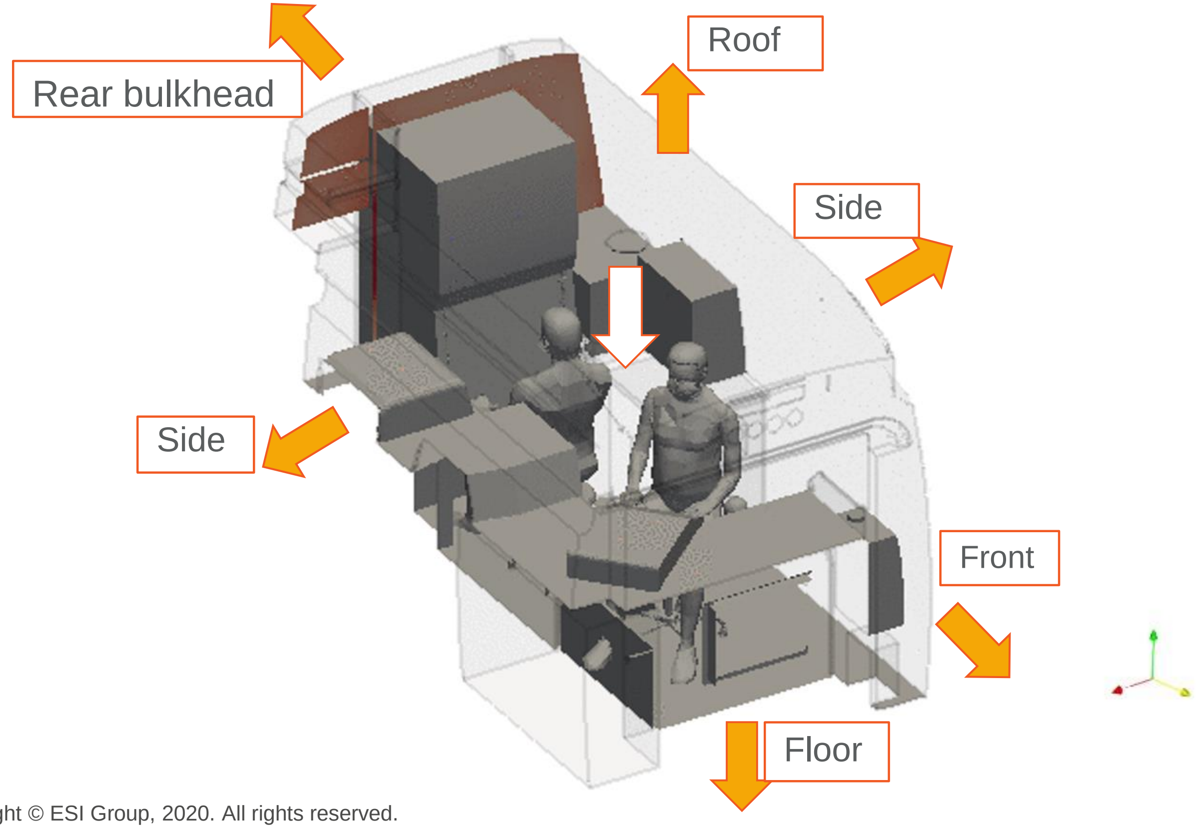
NHS

- Operation:
    - Rapid testing of COVID-19 samples at mobile sites across the UK.
    - These Mobile Processing Units (MPUs) are fitted with LAMP (Loop-mediated Isothermal Amplification) equipment, in highly controlled environments designed to maintain strict temperatures and circulate fresh air to minimise cross-contamination and risk to their operators.

Mobile Processing Units Commissioning

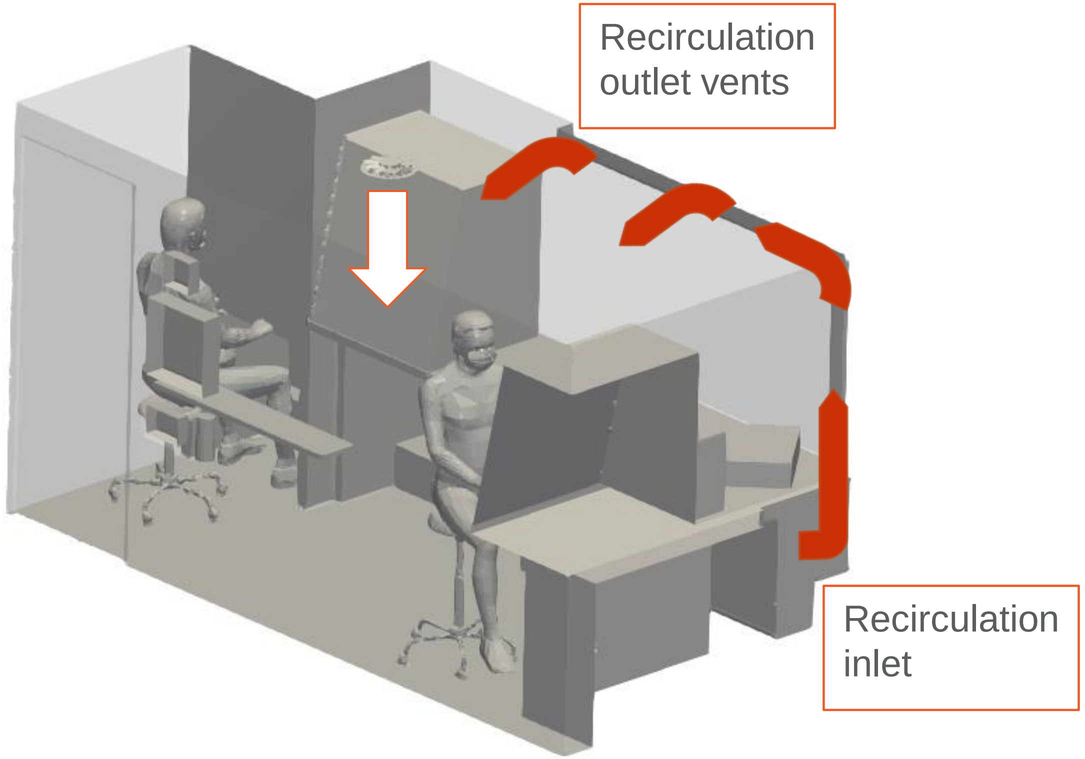
Van – safe ventilation & equipment temperatures

- Fresh air roof intake for **occupancy ventilation**
- Heater mixing to **maintain required equipment temperatures**



Trailer – ventilation and equipment environment

- Fresh air roof intake for **occupancy ventilation**
- Auxiliary recirculation away from key equipment to **maintain calm air processing environment**



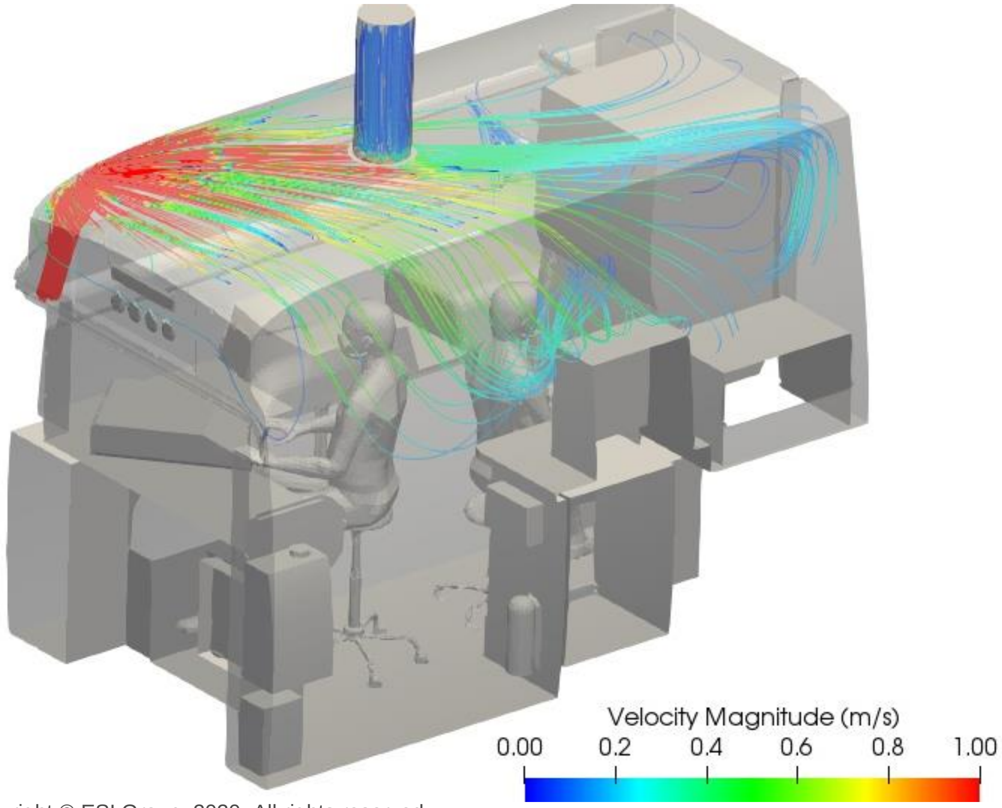
Ventilation and heating streamlines – velocity magnitude

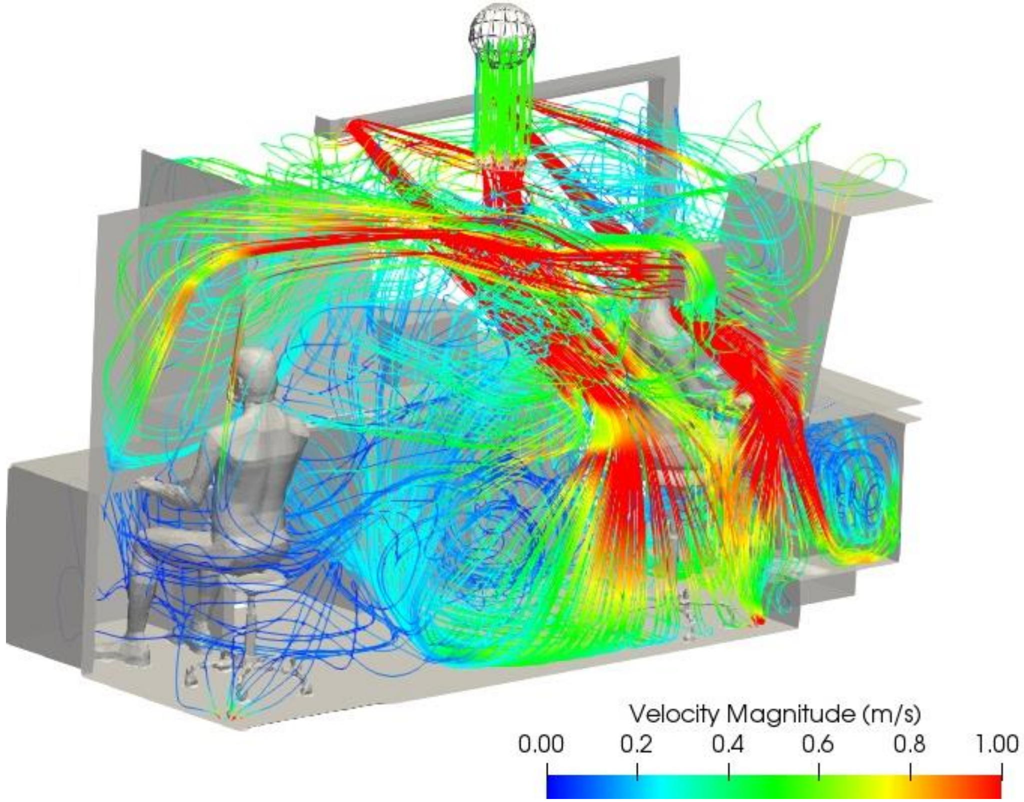
Van – safe ventilation & equipment temperatures

- Fresh air roof intake for **occupancy ventilation**
- Heater mixing to **maintain required equipment temperatures**

Trailer – ventilation and equipment environment

- Fresh air roof intake for **occupancy ventilation**
- Auxiliary recirculation away from key equipment to **maintain calm air processing environment**





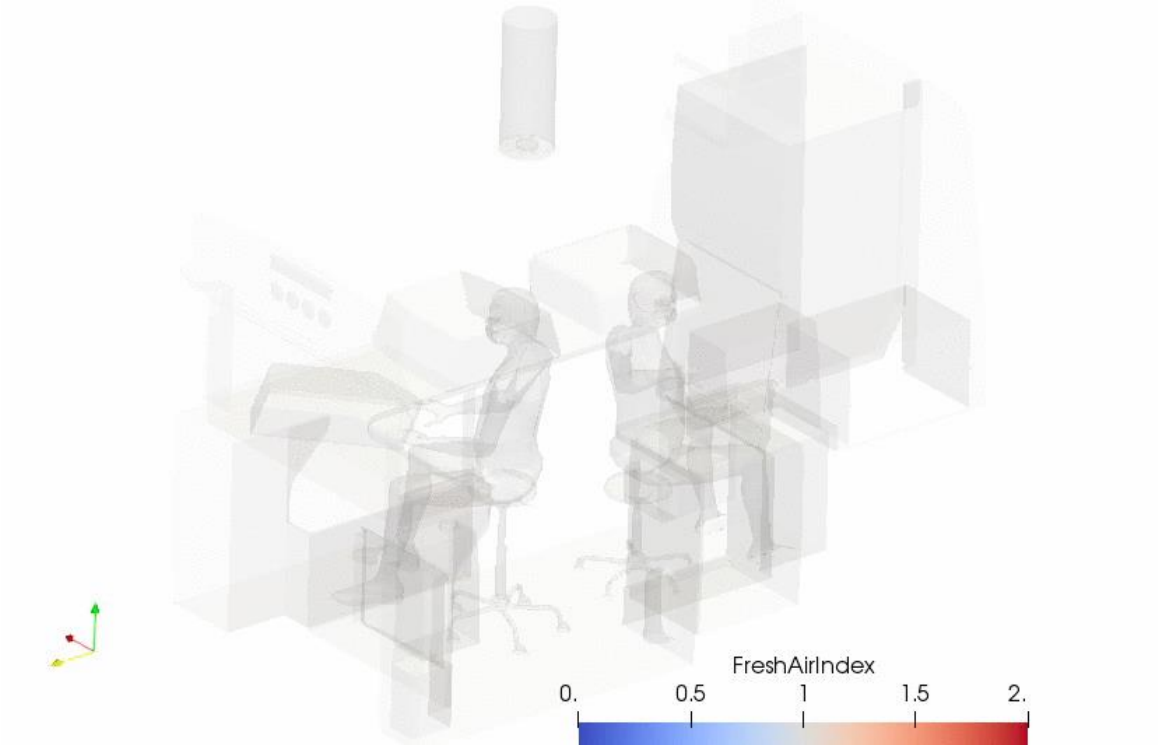
Fresh Air Environment

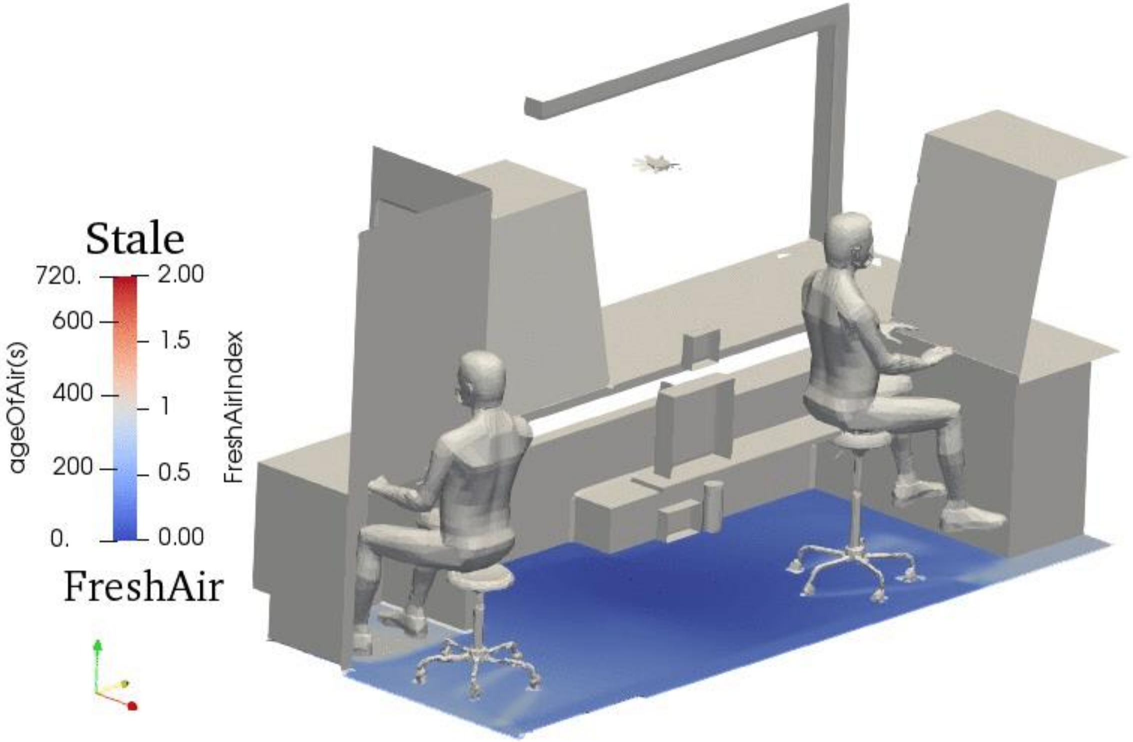
Van – safe ventilation & equipment temperatures

- Fresh air roof intake for **occupancy ventilation**
- Heater mixing to **maintain required equipment temperatures**

Trailer – ventilation and equipment environment

- Fresh air roof intake for **occupancy ventilation**
- Auxiliary recirculation away from key equipment to **maintain calm air processing environment**





Customer Sign-off - Statement of value

RE: MPU(V) CFD - statement of need and value

CR

Carter, Ross <Ross.Carter@[redacted]

Fri 22/01/2021 09:59

To: Fred Mendonca

To whom it may concern,

Mobile Processing Unit

An engineering team from the military were activated to support the Department of Health and Social Care (DHSC) design and build mobile processing laboratories.

These units have been designed and built in unprecedented time, learning new concepts and processes not just in COVID-19 processing but the adaptability of static laboratory testing equipment for mobile use and the interpretation of regulations and emerging technical information regarding the SAR-COVID pathogen.

This emerging technical information, left a hole in our knowledge and development, which posed a significant risk to the development of our project. As a small team we had minimal leavers of understanding the risk or more importantly articulating the possible risks.

Working with Fred and his team we have been able to break apart the possible problems posed by Air flow development within our platforms. Daily engineering decision we were making to the platform, posed a significant impacts somewhere else in the design. Working with CFD, analysing the airflow and understanding the problem has allowed us to de-risk a number of significant areas of concern and more importantly has provided the team a body of evidence to the Chief Scientific Officer, NHS and their team that these platforms are developed appropriately.

Fred and his team have been instrumental in the success of this project, their support has been 100% and I could have not asked for more.

Yours sincerely,

Major Ross Carter REME
Engineering Officer
Royal Electrical and Mechanical Engineering

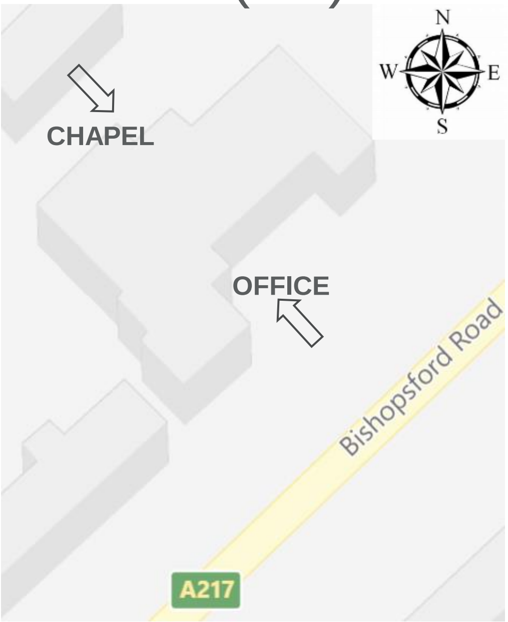
Department of Health & Social Care

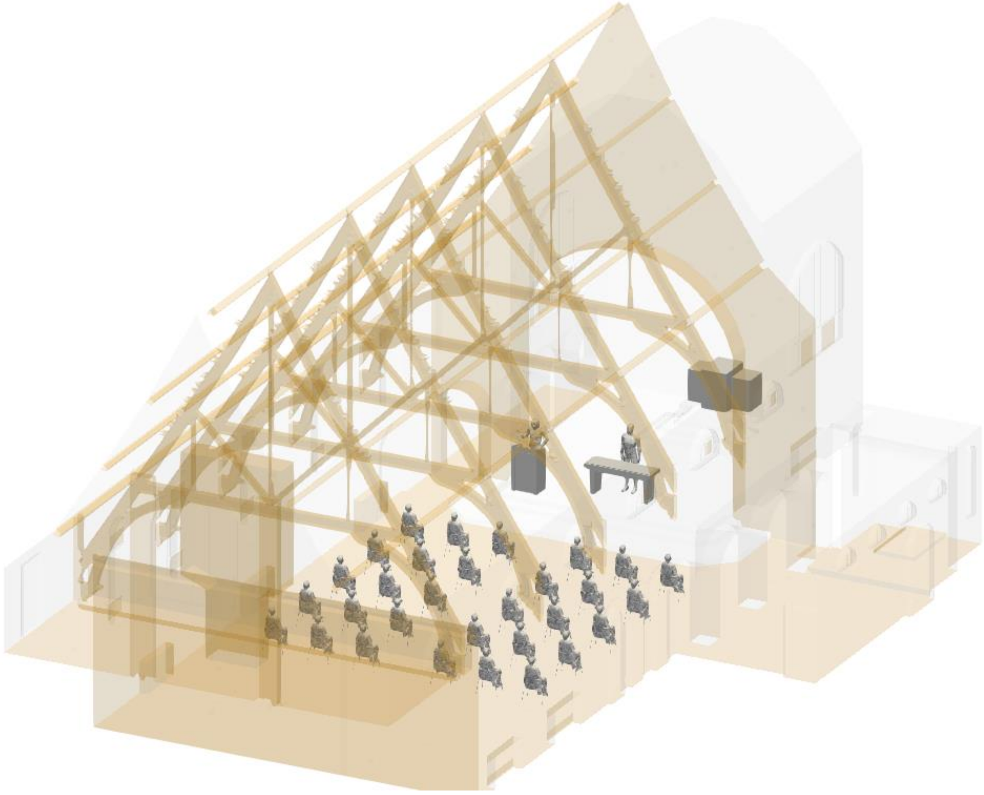
Major Ross Carter
Military Embed to DHSC
Department of Health and Social Care
39 Victoria Street, London, SW1H 0EU
Mobile: [redacted]
VOIP: +[redacted]
Email ross.carte[redacted]
MoD ross.carter[redacted]

Community Centre:

St. Teresa's Church, in the RC Archdiocese of Southwark

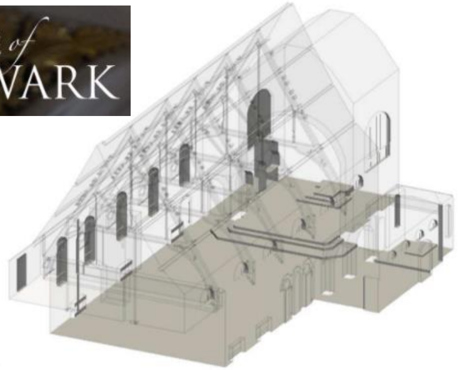
- Footfall approx. 1000 persons per week
  - Ventilation effectiveness and wellbeing
- Two scenario were simulated
  - Without occupants and furniture
  - With occupants
- Wind blowing from Office (SE) side or Lady Chapel (NW) side



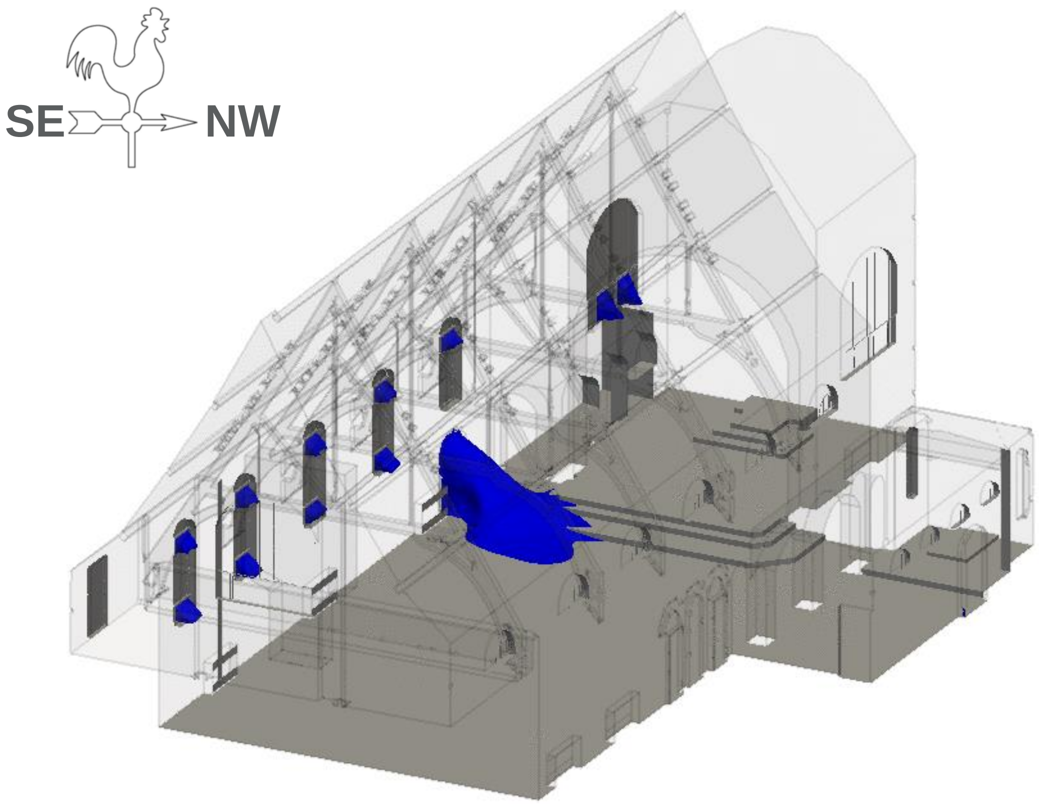


Community Centre: Church

Westerly and Easterly wind – ventilation effectiveness



Iso Surface of Age of Air at 10 secs



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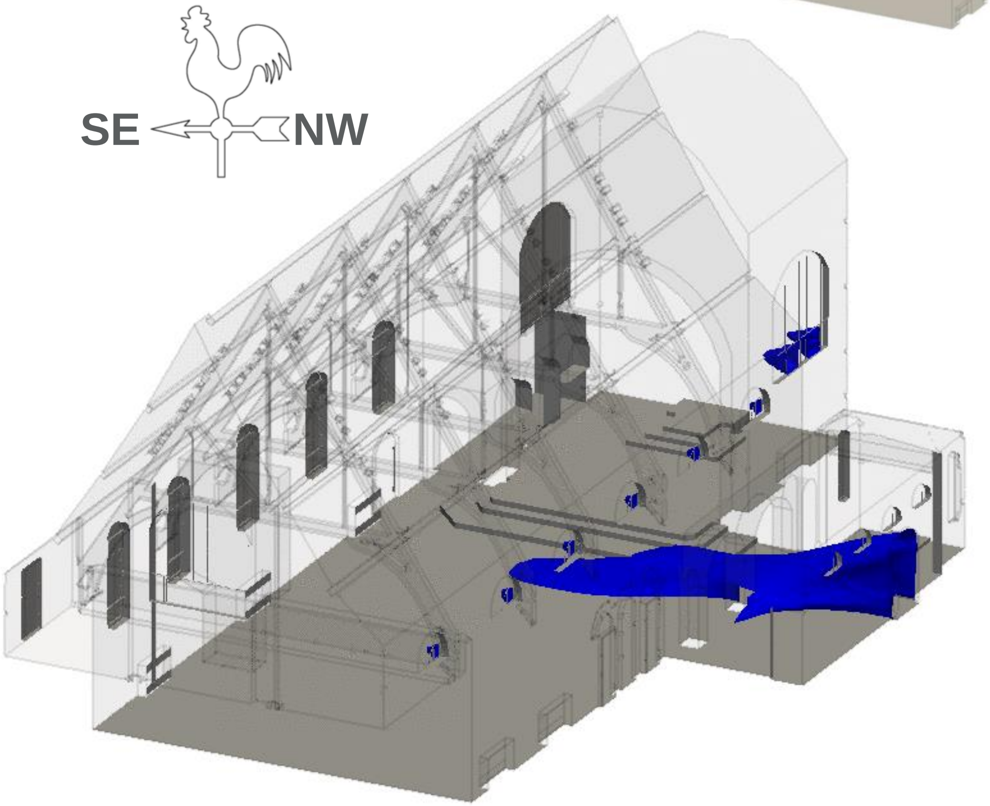
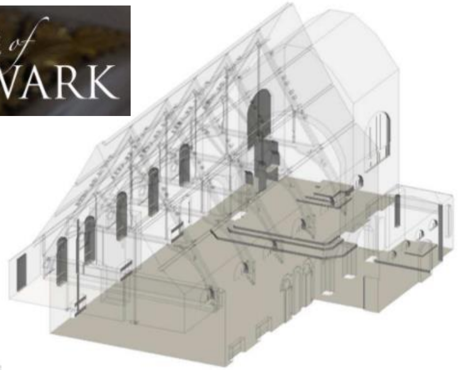
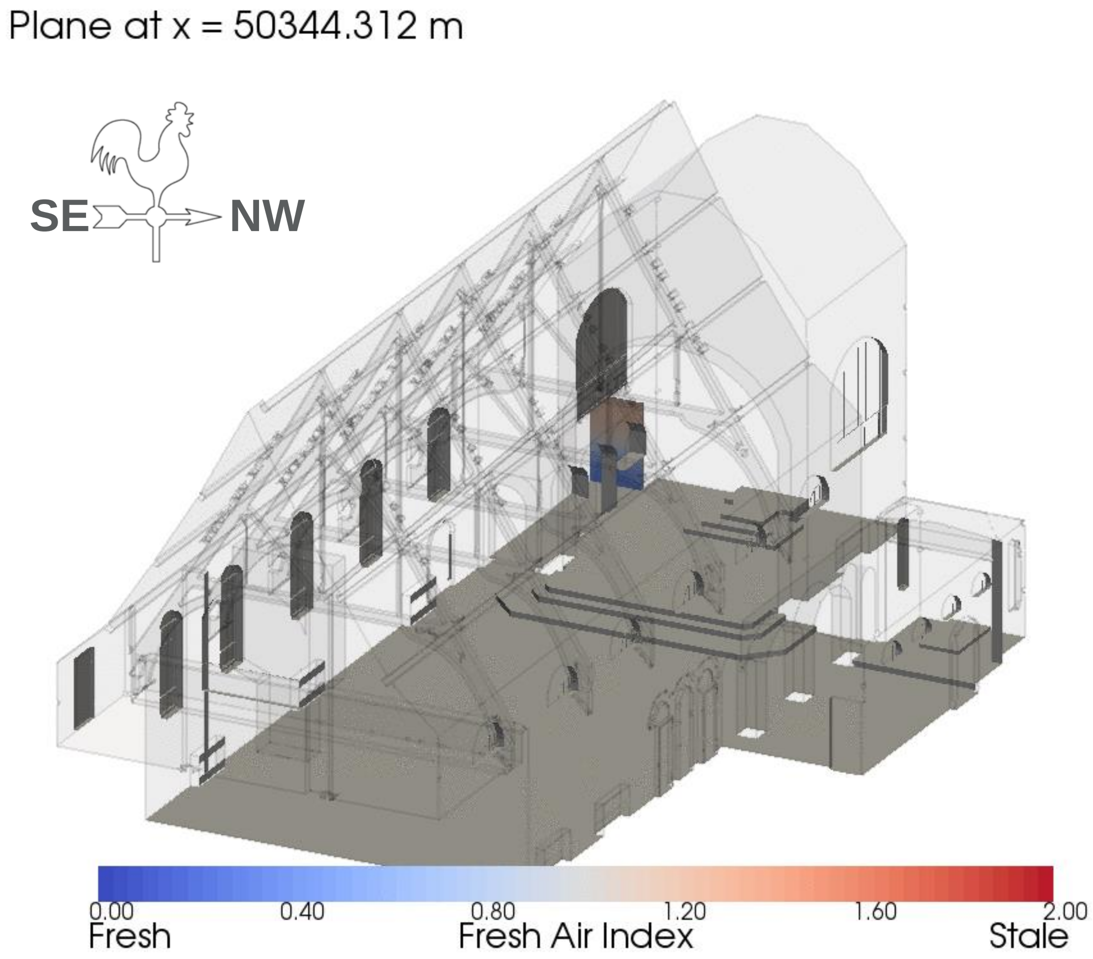
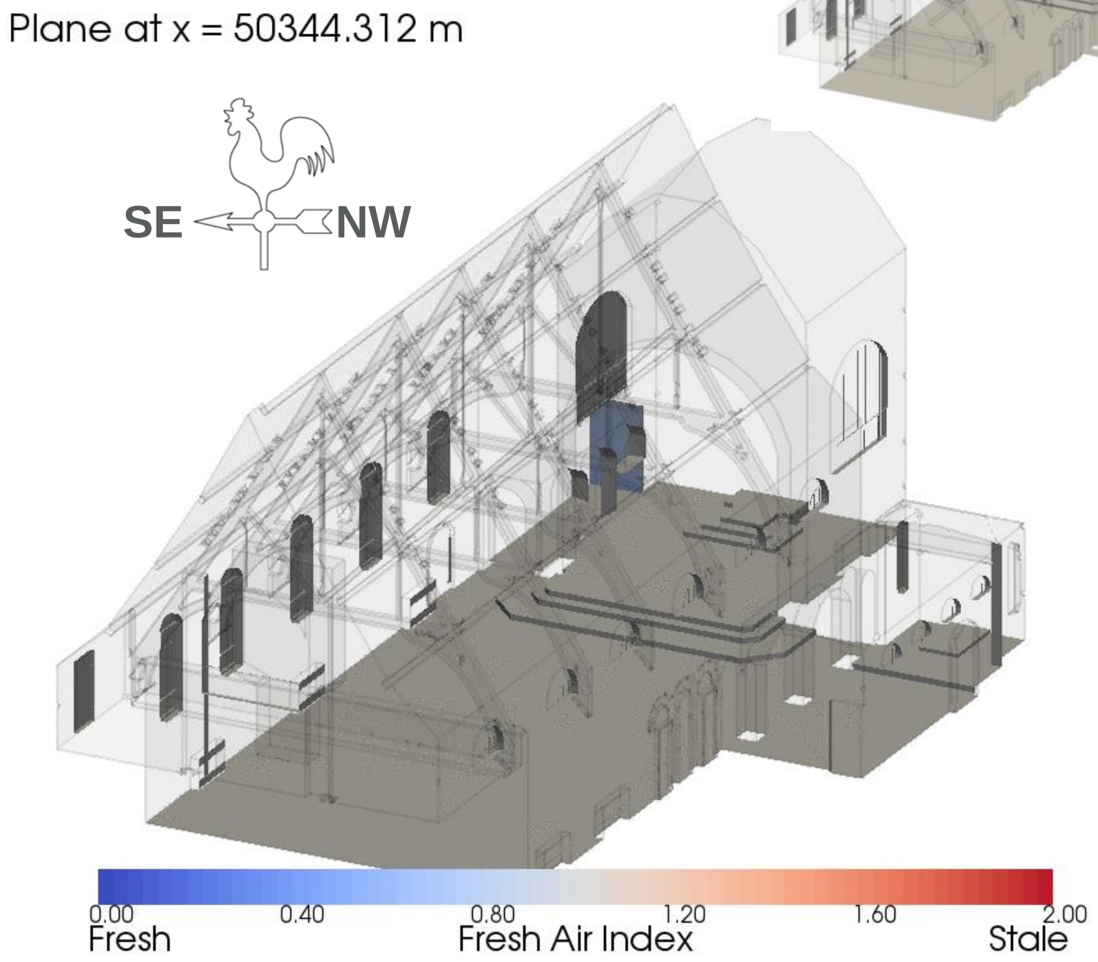


Community Centre: Church

Westerly and Easterly wind – ventilation effectiveness



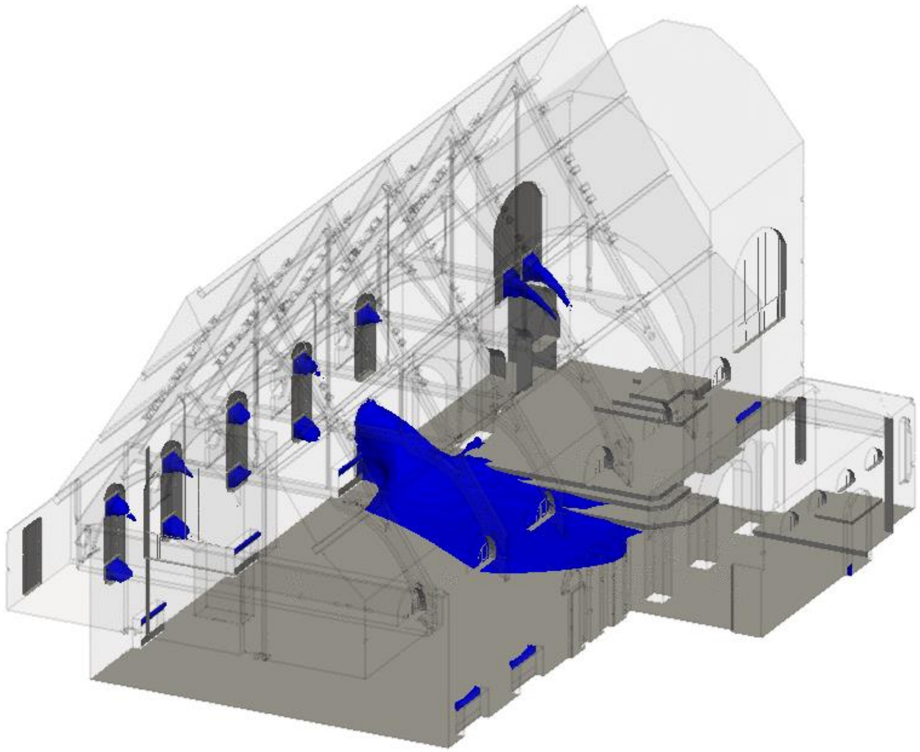




Comparison w/o and w/occupants

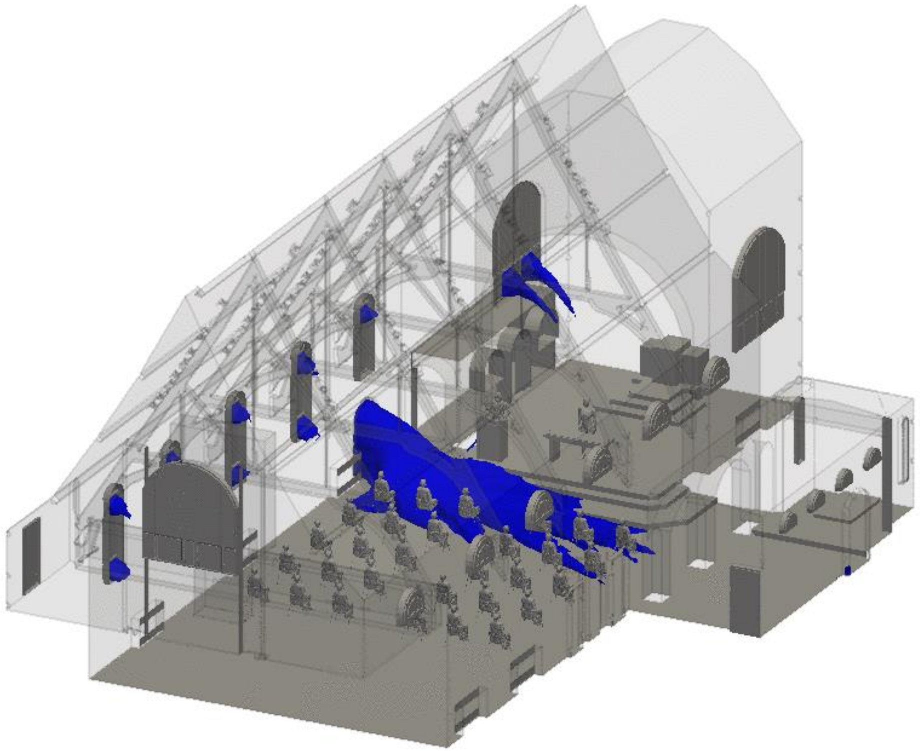
Without occupants

Iso Surface of Age of Air at 10 secs



With occupants

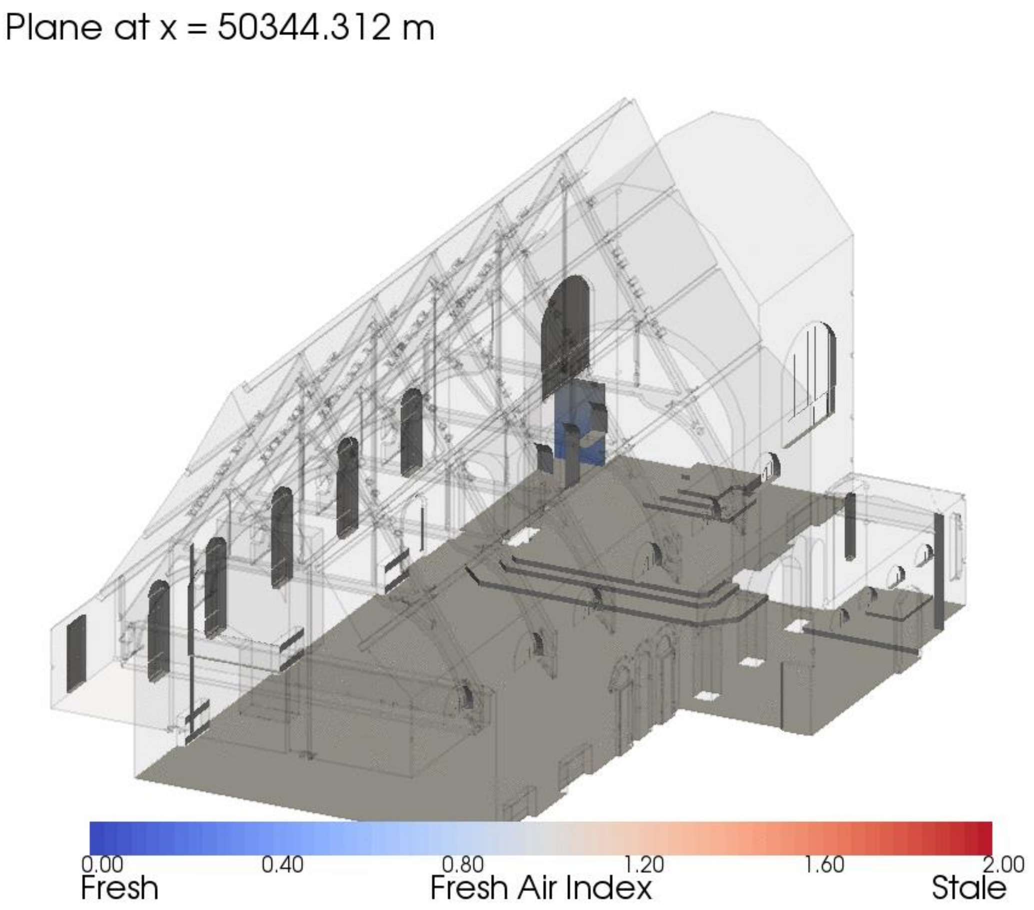
Iso Surface of Age of Air at 10 secs



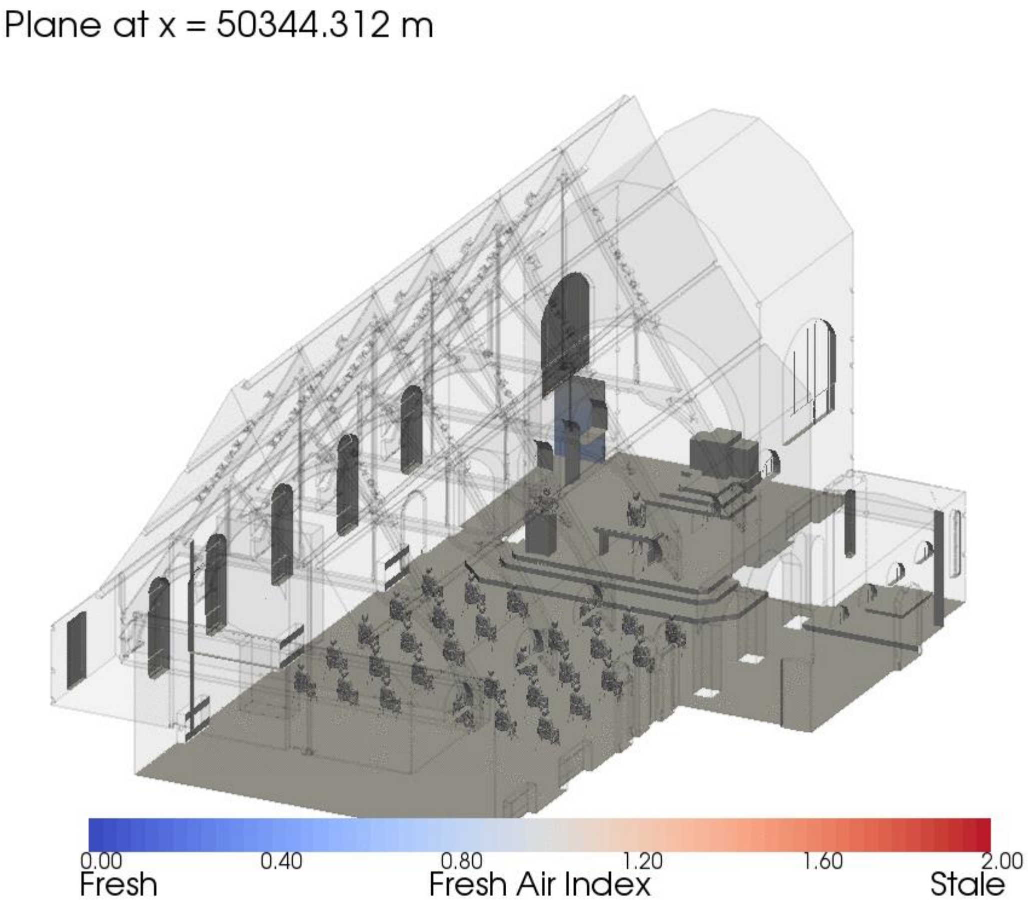
Comparison w/o and w/occupants

SE NW

Without occupants

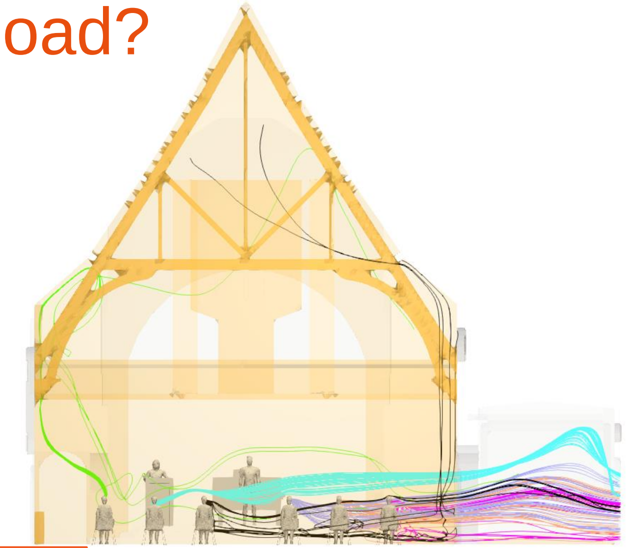


With occupants

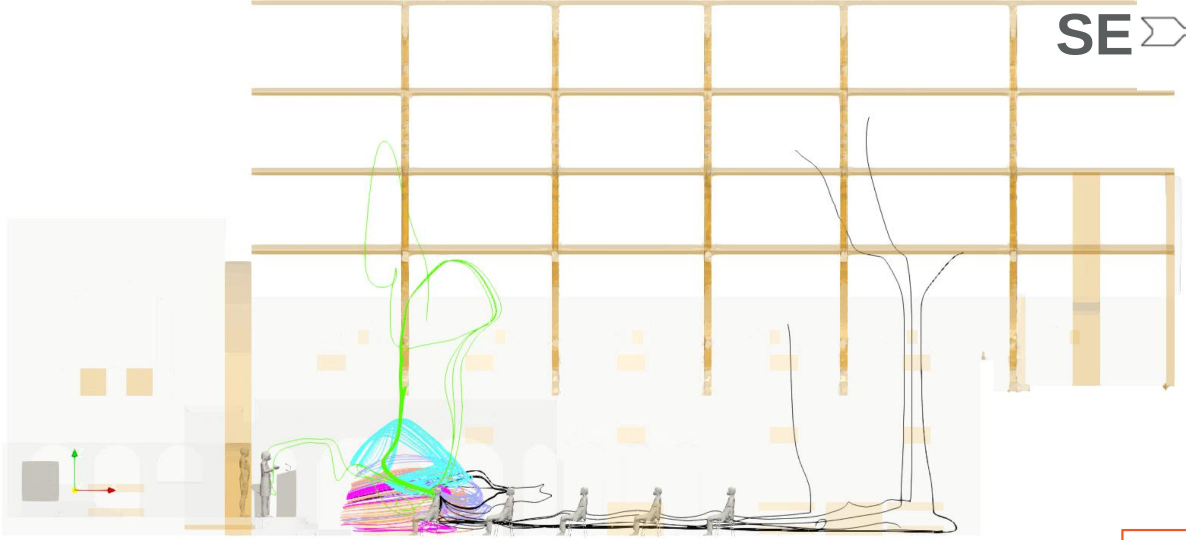


Streamlines for occupant: 1st Row

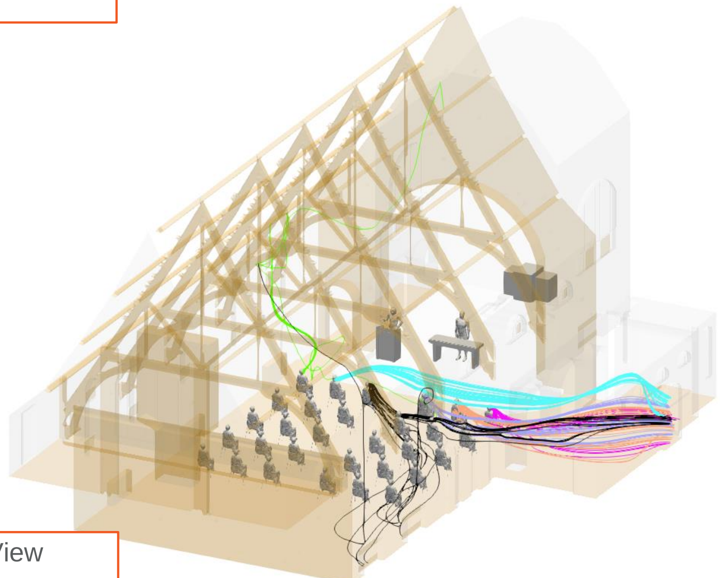
Viral load?



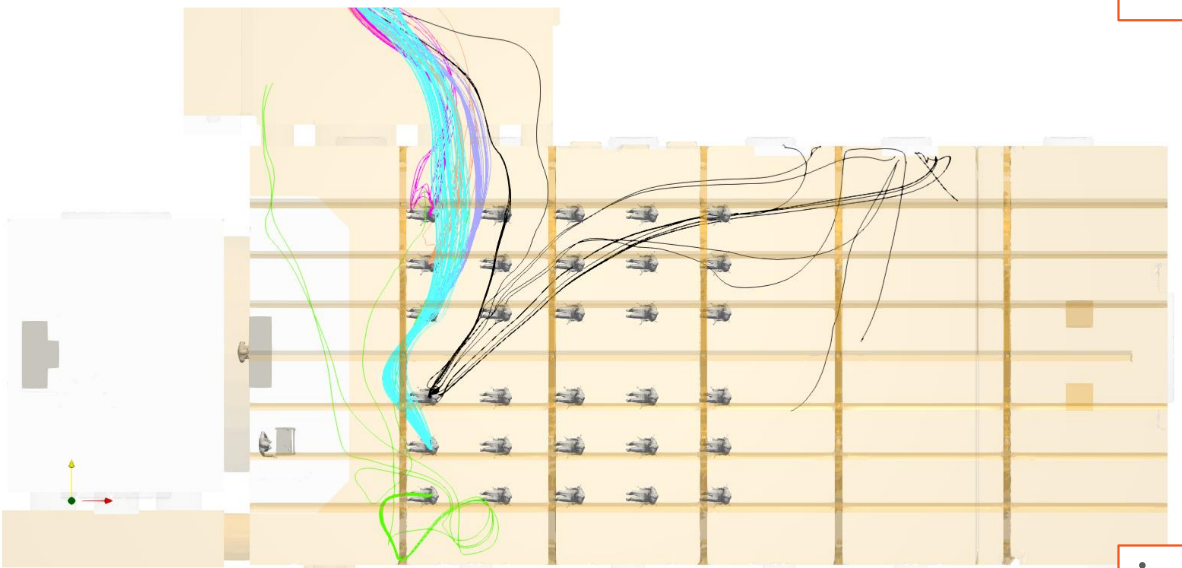
- Rear View



- Side view



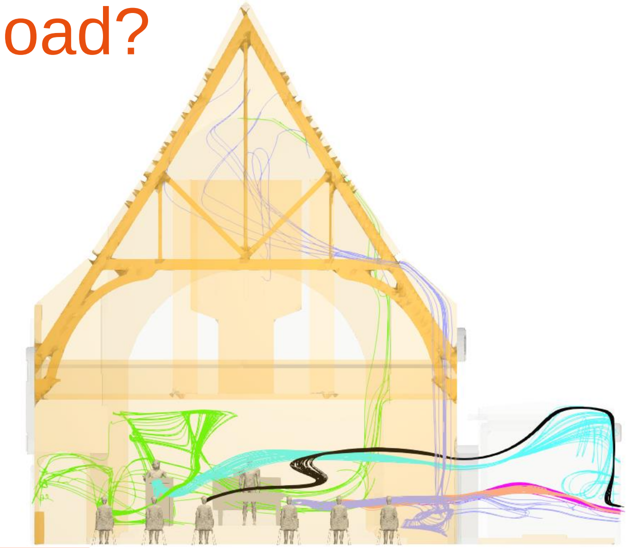
- Isometric View

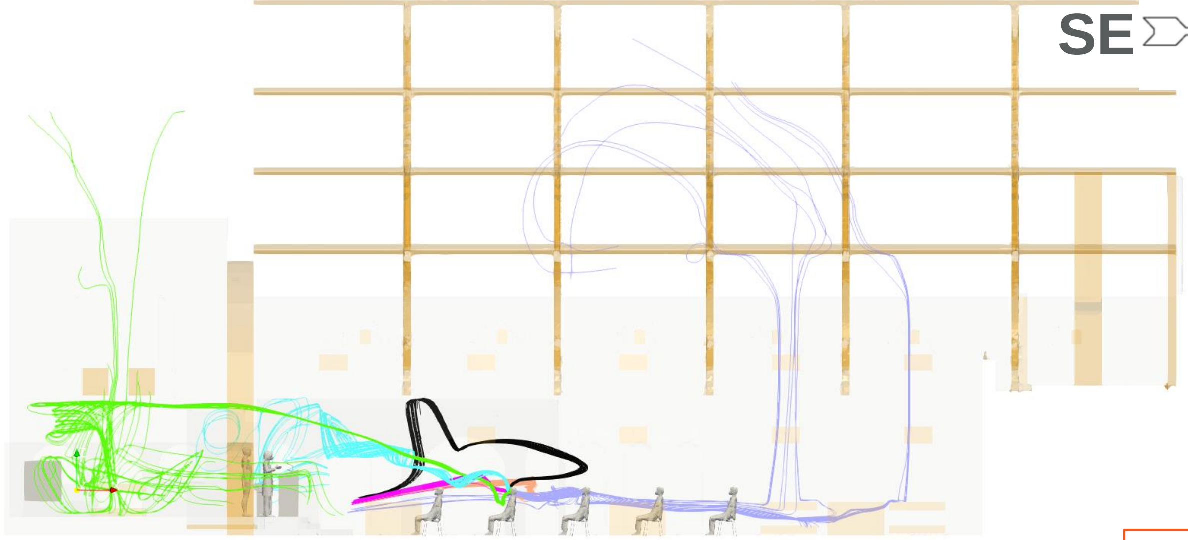


- Top View

Streamlines for occupant: 2nd Row

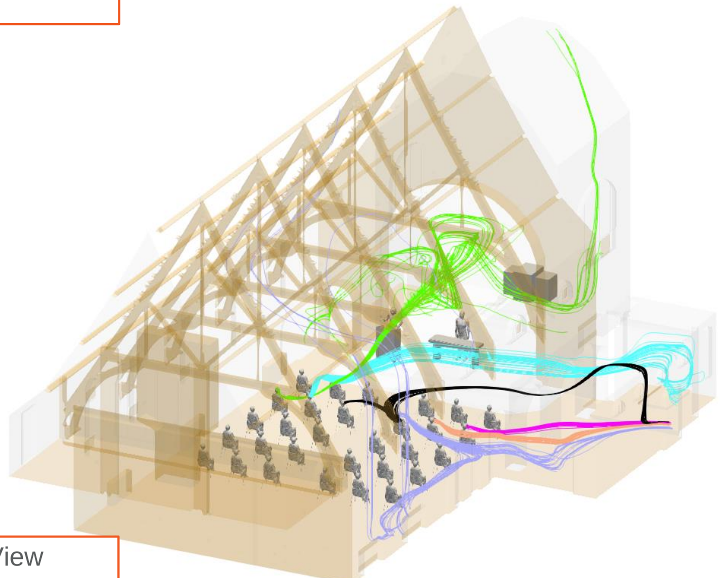
Viral load?

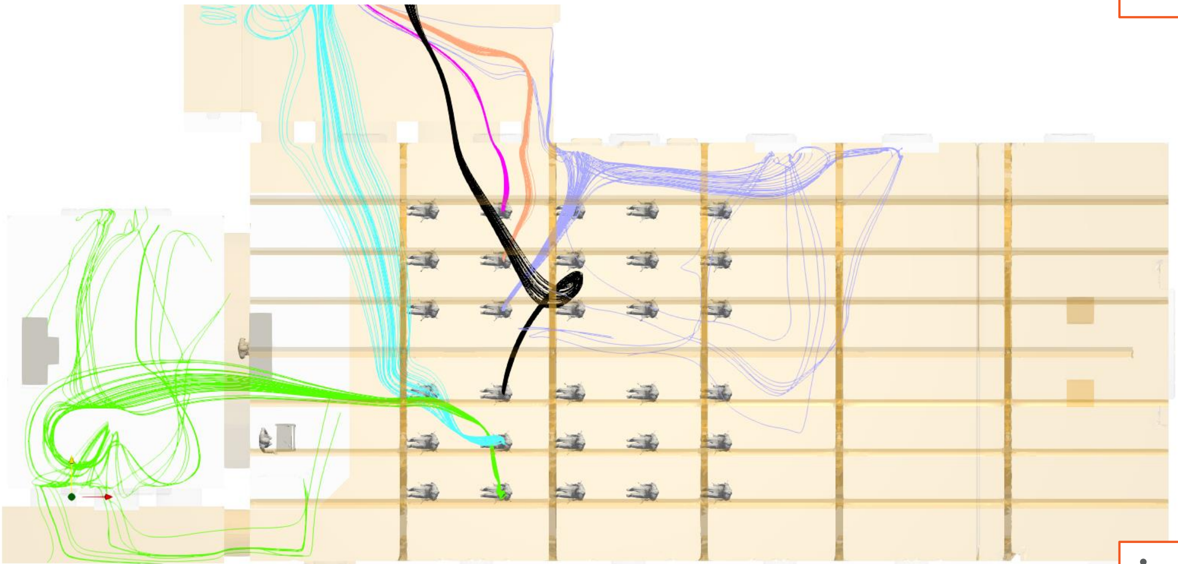




- Rear View

- Side view





- Isometric View

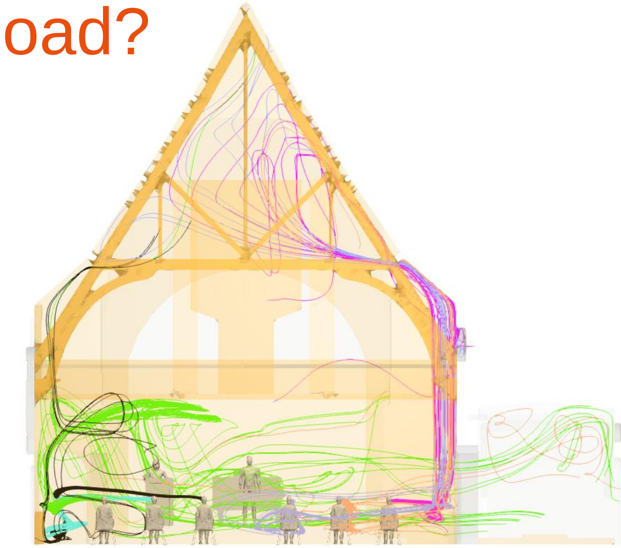
- Top View

ARCHDIOCESE of SOUTHWARK

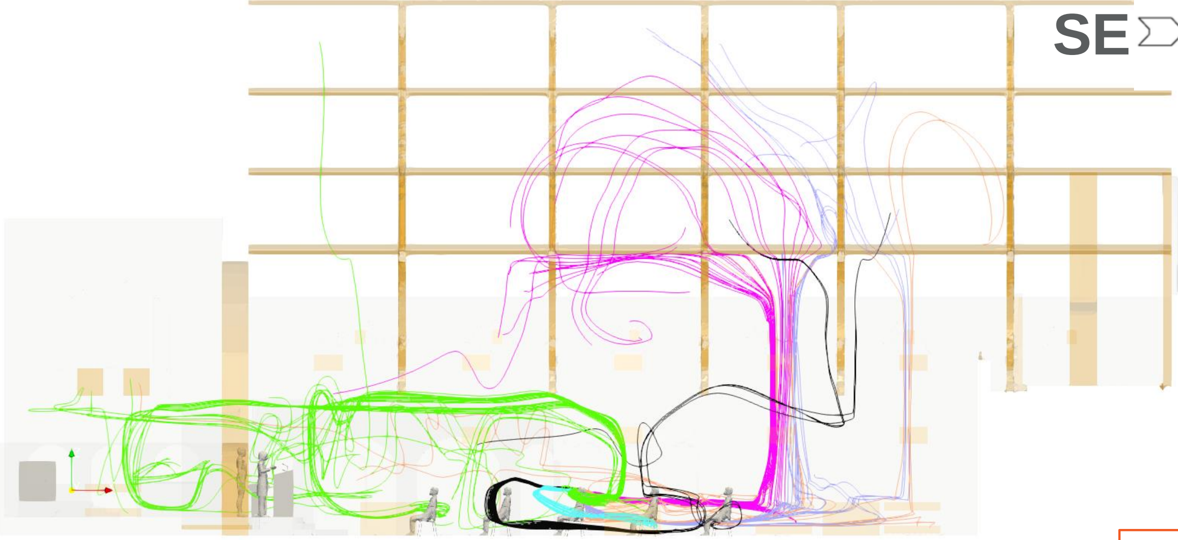
Streamlines for occupant: 3rd Row

Viral load?

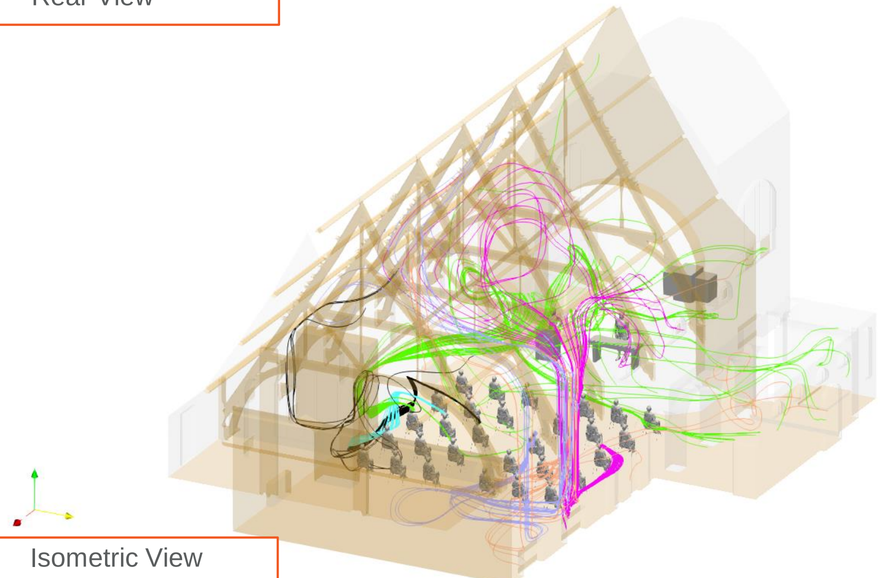
SE NW



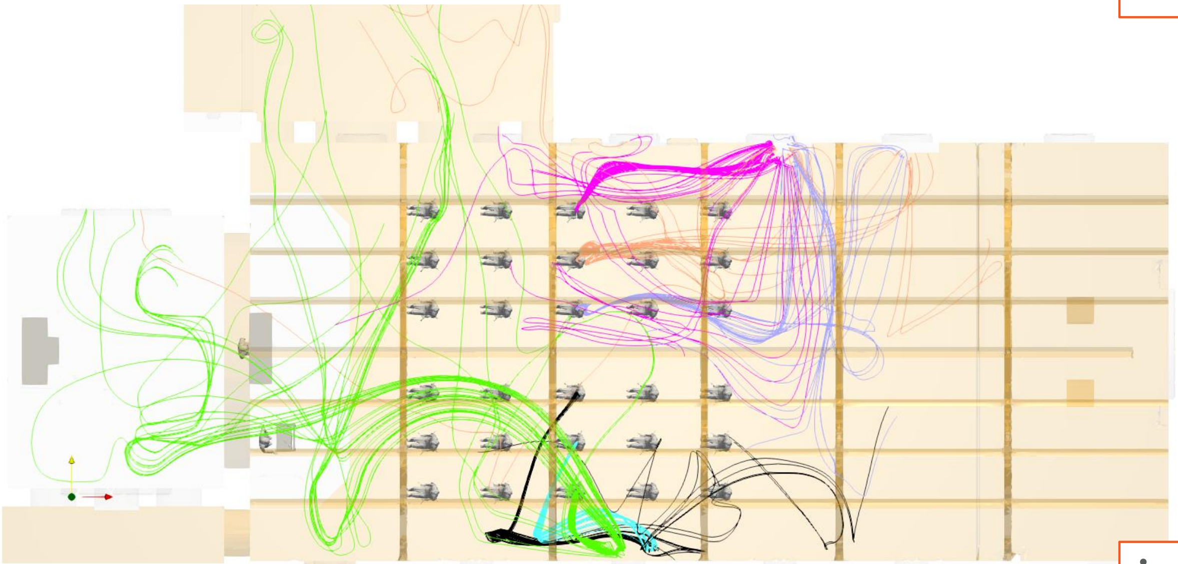
- Rear View



- Side view



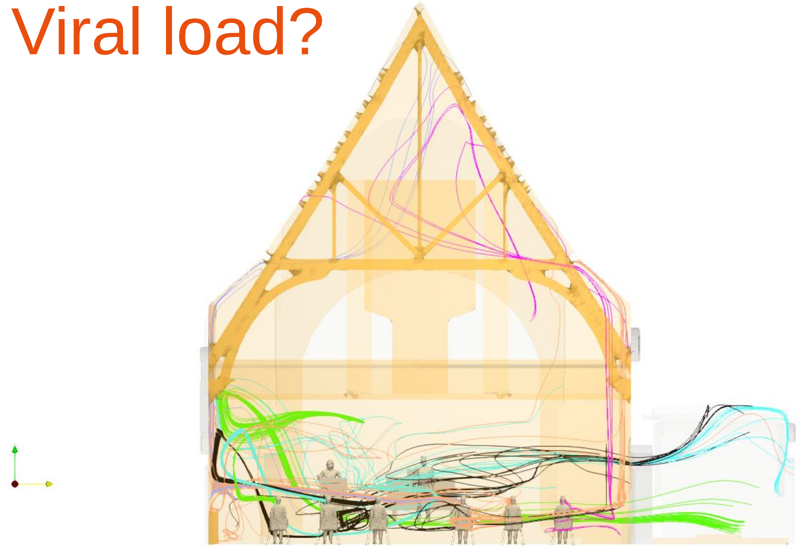
- Isometric View



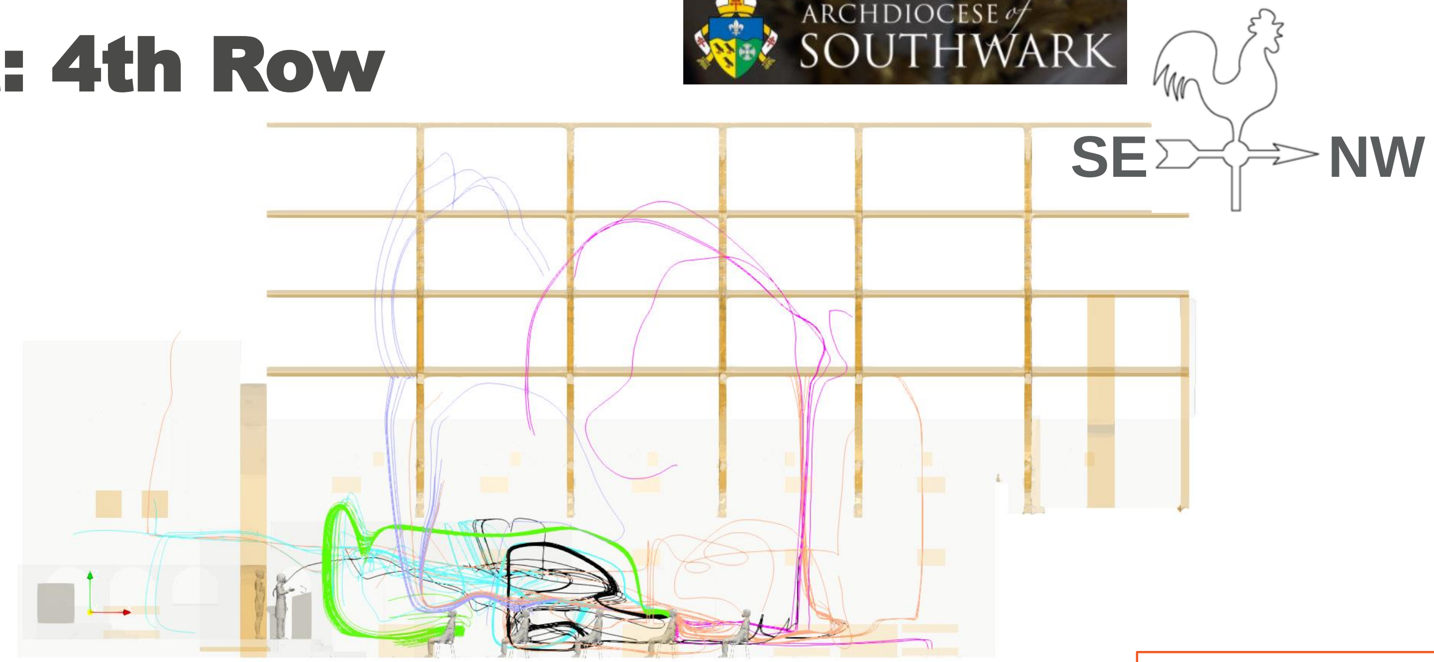
- Top View

Streamlines for occupant: 4th Row

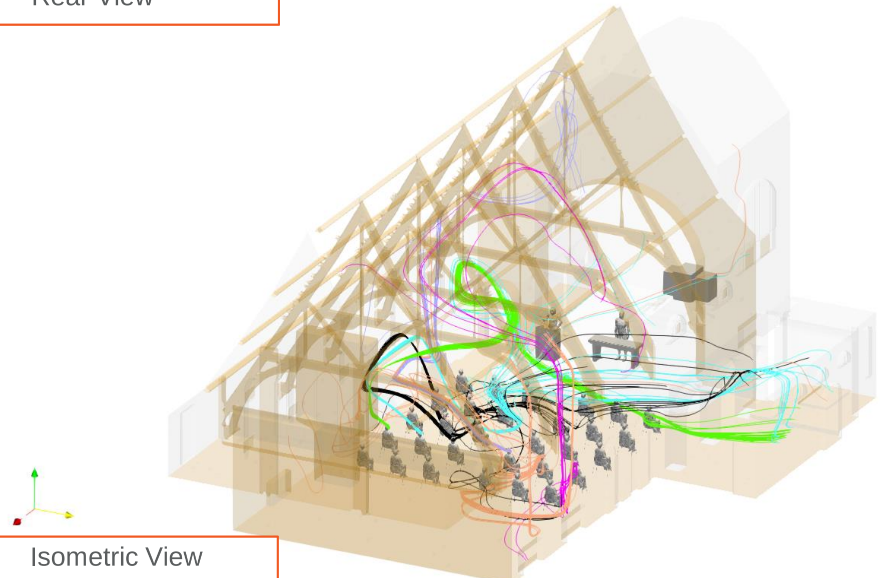
Viral load?



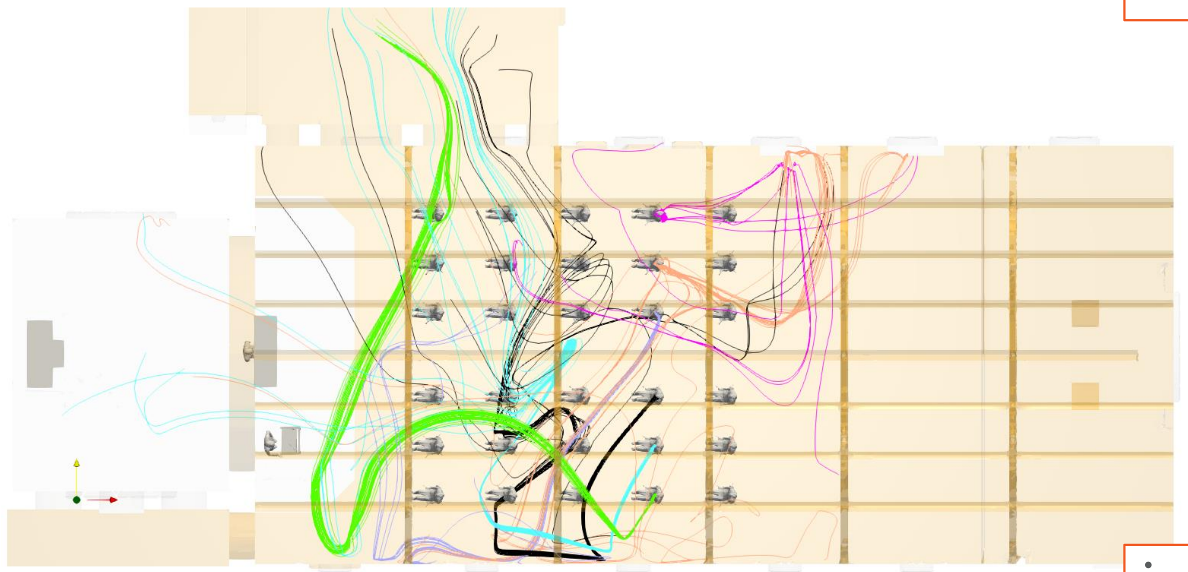
• Rear View



• Side view



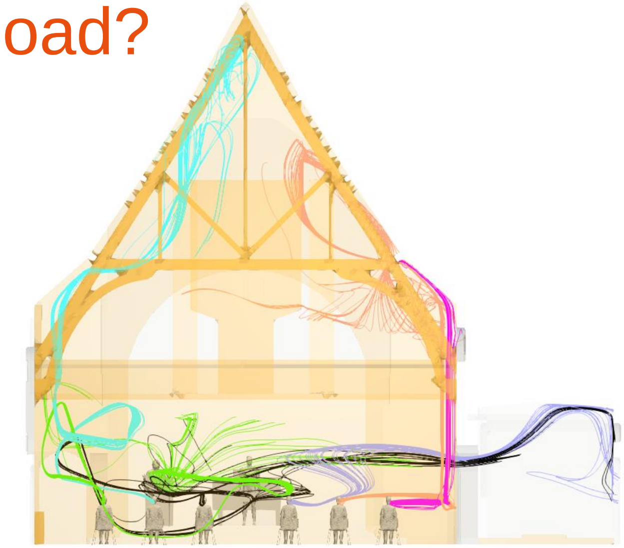
• Isometric View



• Top View

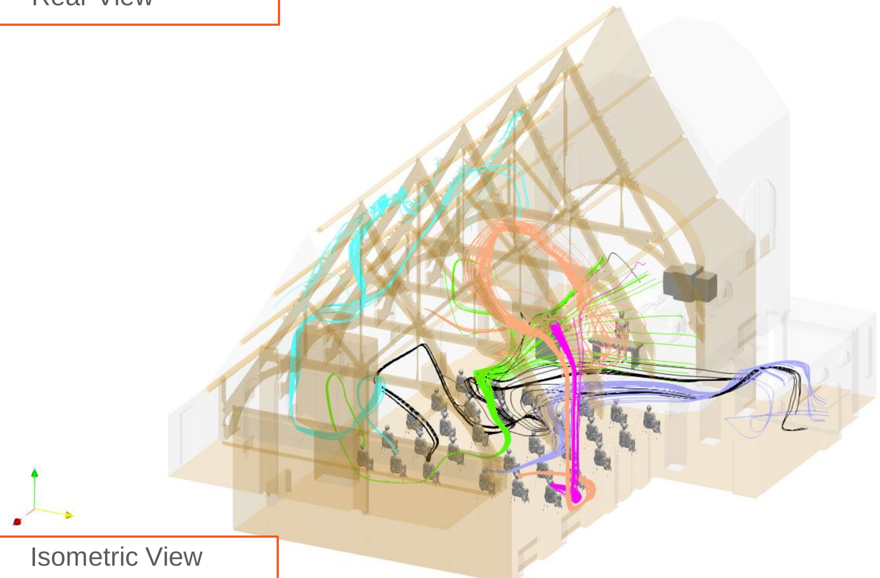
Streamlines for occupant: 5th Row

Viral load?

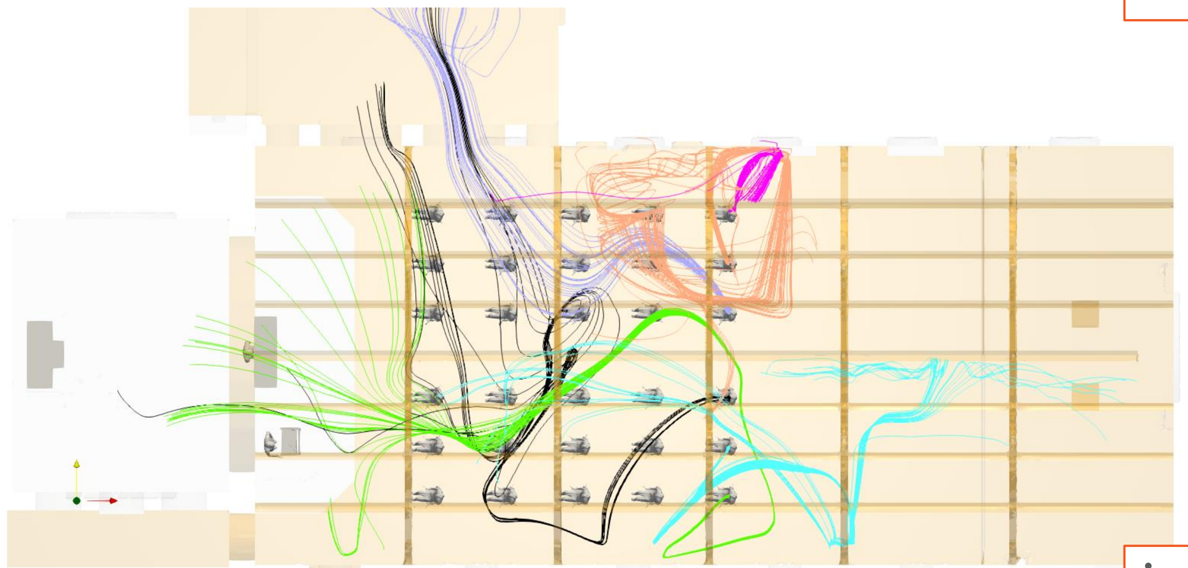


- Rear View

- Side view



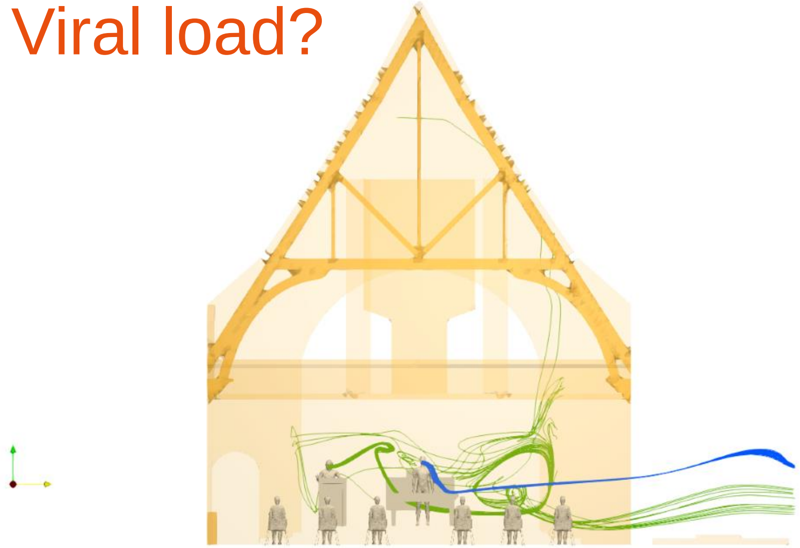
- Isometric View



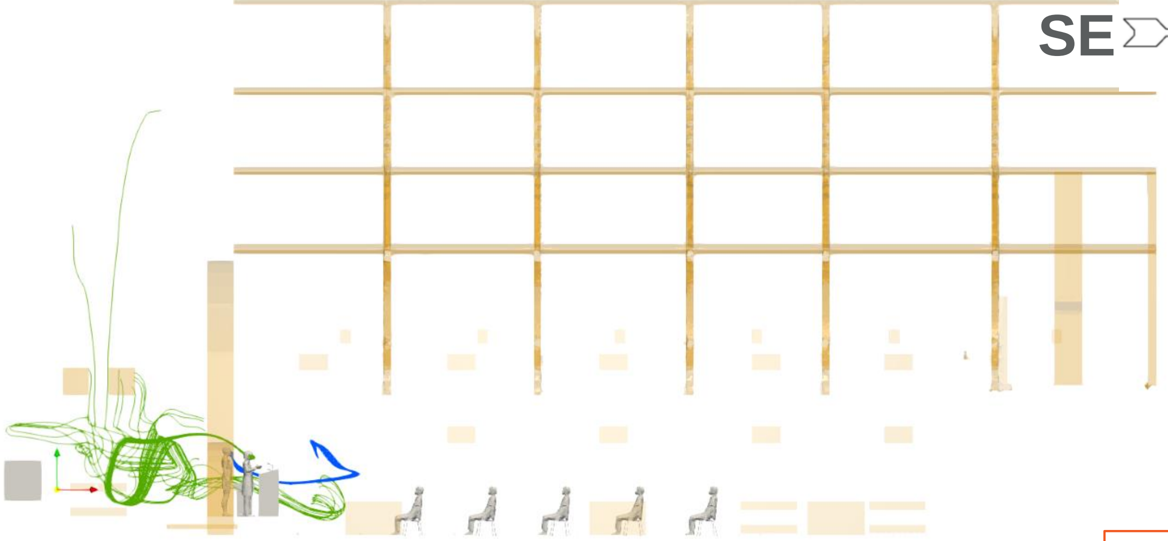
- Top View

Streamlines for occupant: from Sanctuary

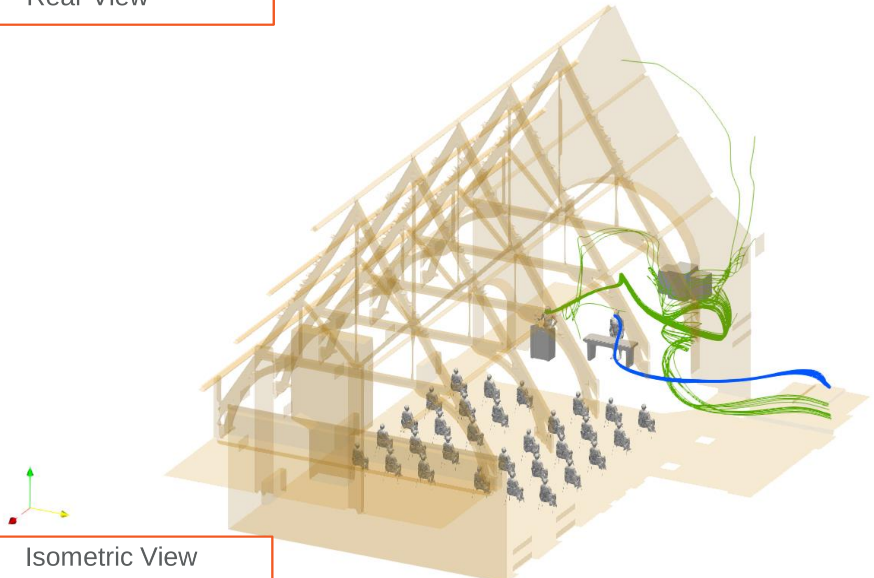
Viral load?



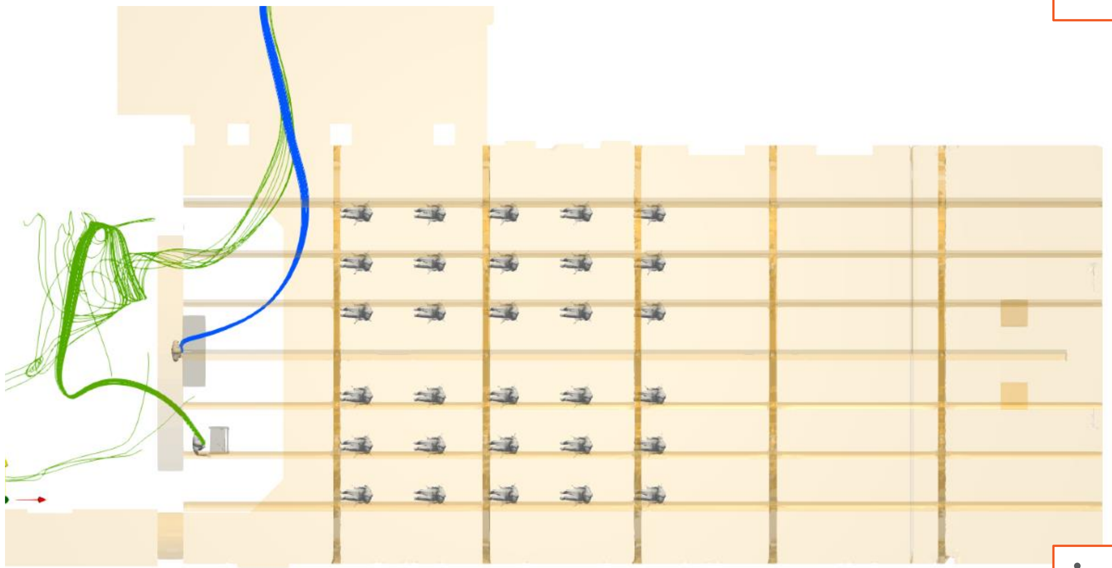
- Rear View



- Side view



- Isometric View



- Top View

The Team – assessing Fallow time and use of "Scrubbers"

UK-wide NHS Clinical Engineering informing CSO/PHE/SAGE on dental AGP

Professor Tony Fisher *MBE MD MSc PhD FAHCS FIPEM FInstP FIET CEng CSci CPhys*
Head of Department**, *Dept. of Medical Physics & Clinical Engineering***
Royal Liverpool University Hospital
Trust Lead Scientist
Director Merseyside Training Consortium for Medical Physics & Clinical Engineering
Head of Department*, Dept. of Medical Physics & Clinical Engineering*
Royal Liverpool University Hospital

Fred Mendonça
Director, Physics Modelling
Innovation and Discovery
MD, OpenCFD Ltd

Claire Greaves
Chief Scientist & Clinical Director
Head of Medical Physics and
Clinical Engineering
Nottingham University Hospitals NHS Trust

Professor Paul White
Head of Clinical Engineering
Cambridge University Hospitals
NHS Foundation Trust

Frank Mills, FCIBSE, MASHRAE
Chair*, CIBSE Healthcare Group*
Founder member *of IMechE Covid 19 Task Force*
Member of ASHRAE *Epidemic Task Force*

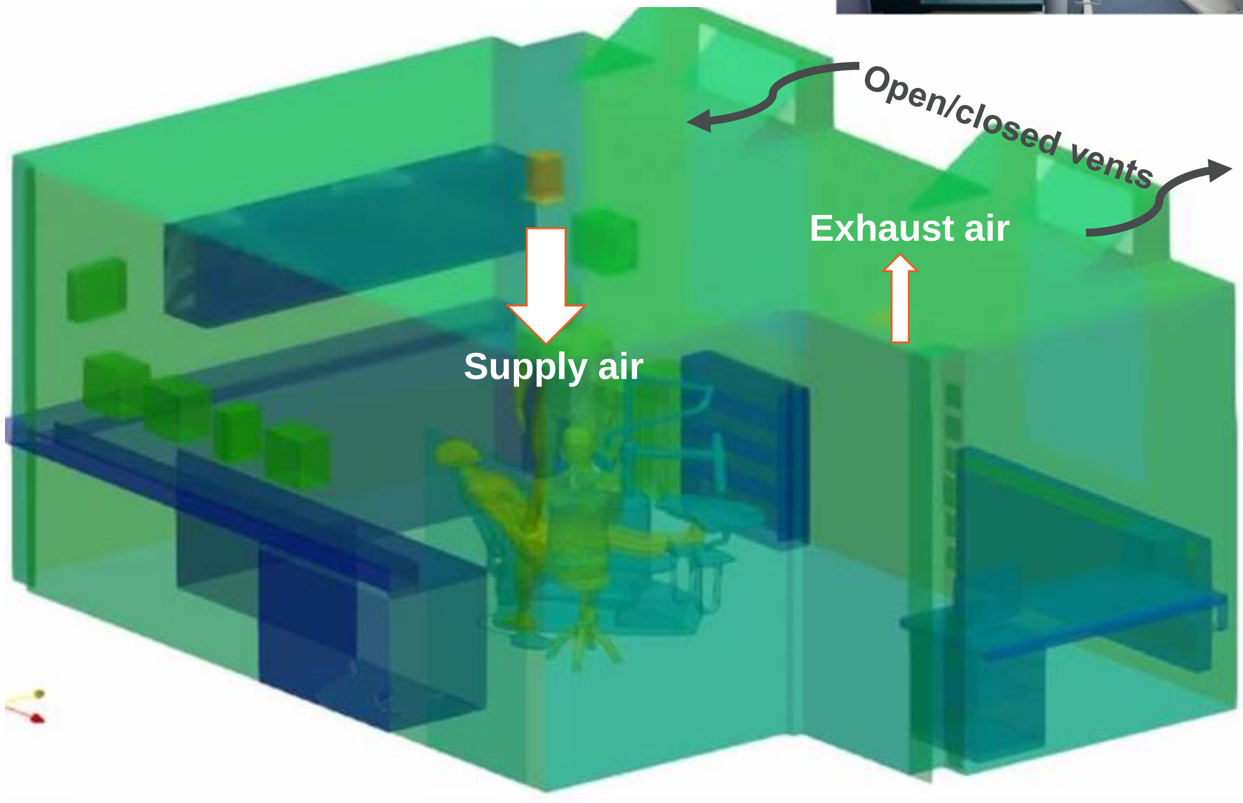
Peter Bill
Head of Neurophysiology
Regional Chief Scientist
Birmingham Women's and
Children's NHS Foundation Trust

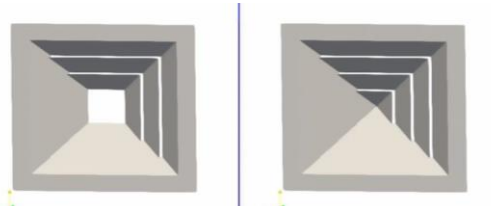
Professor Chris Hopkins
Head of Clinical Engineering
Hywel Dda University Health Board

Dental Treatment Room – Birmingham Children's Hospital

Thermally neutral operating mode

- VERIFIED CFD MODEL
  - Vent air supply @ 5ACpH and extract exactly balanced
    - Treatment room volume is 44.7m^{3},
    - 3 occupants/equipment included
  - Assessing
    - Effects of Air Scrubber (location and rate)
    - Movement of Viral load from AGP
    - Dual direction
      - Roof angled
      - Central jet



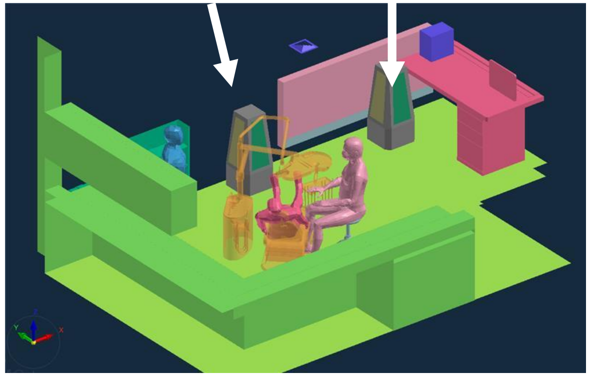


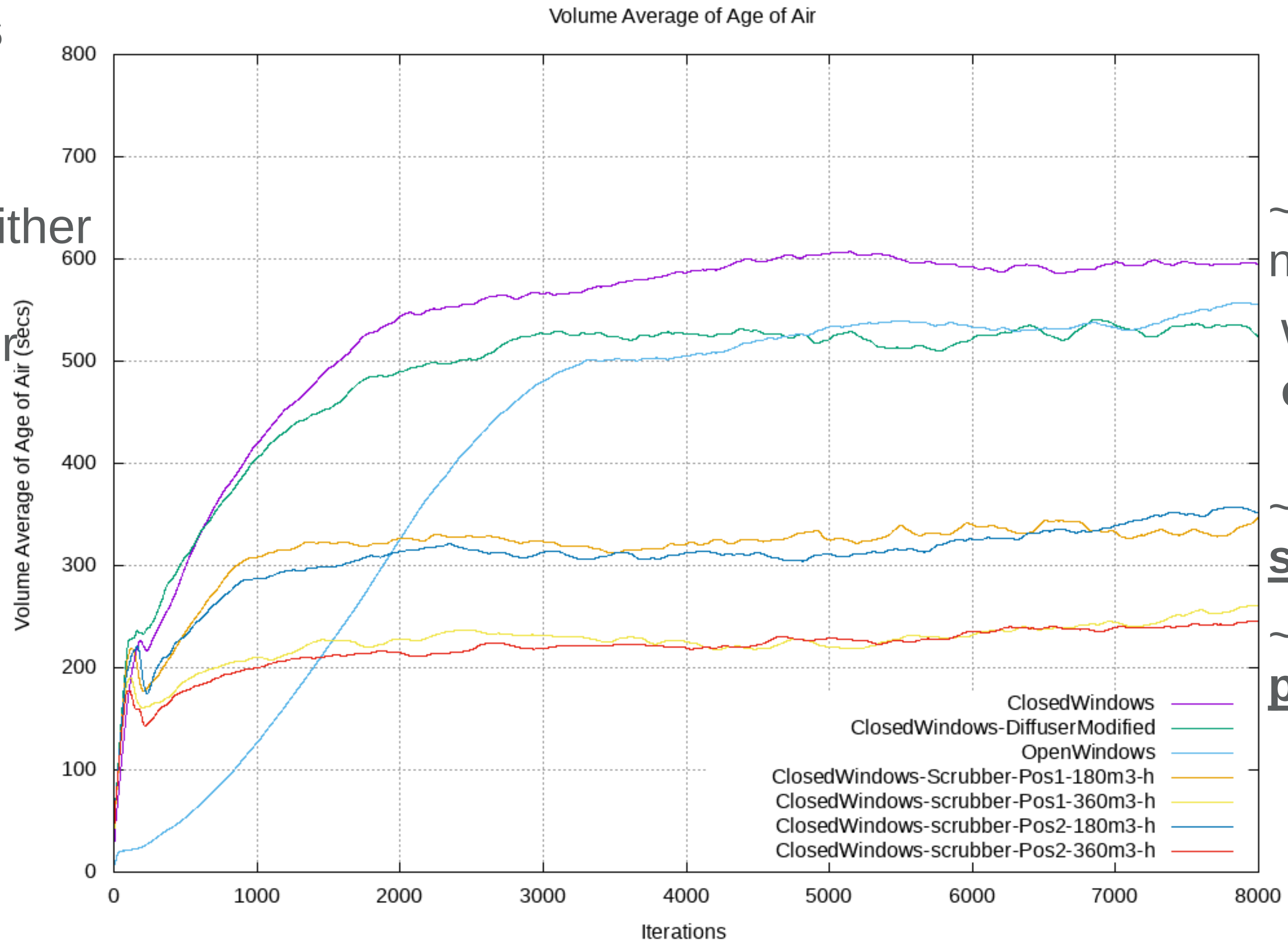
Dental Treatment Room – Birmingham Children's Hospital

Room averaged Age of Air

- No-scrubber - **10 mins**
- UV scrubber in situ
  - **Standard** flow rate (either position) ~ **6 mins**
  - **Purge** flow rate (either position) ~ **4 mins**

Pos-2 Pos-1





~**600**sec (original, no scrubber)

Windows **open, or, central** jet

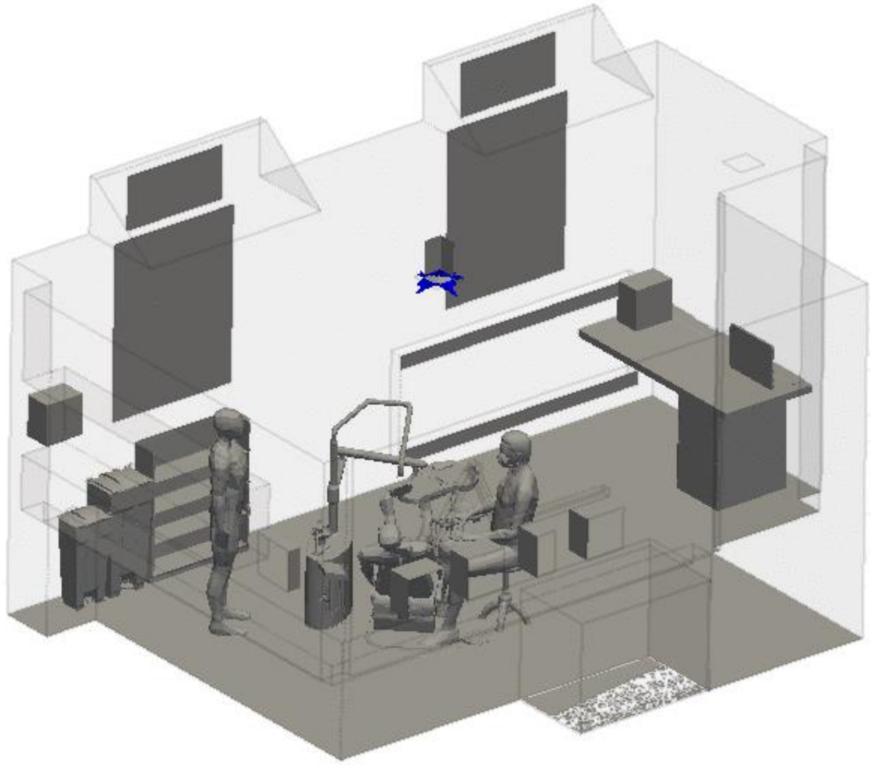
~**350**sec (UV **standard** flow rate)

~**250**sec (UV **purge** flow rate)

Dental Treatment Room – AgeOfAir Isosurfaces (time-advance)

NO SCRUBBER | Thermally neutral operating mode | **360m³/h POS-1**

Iso Surface of Age of Air at 10 secs



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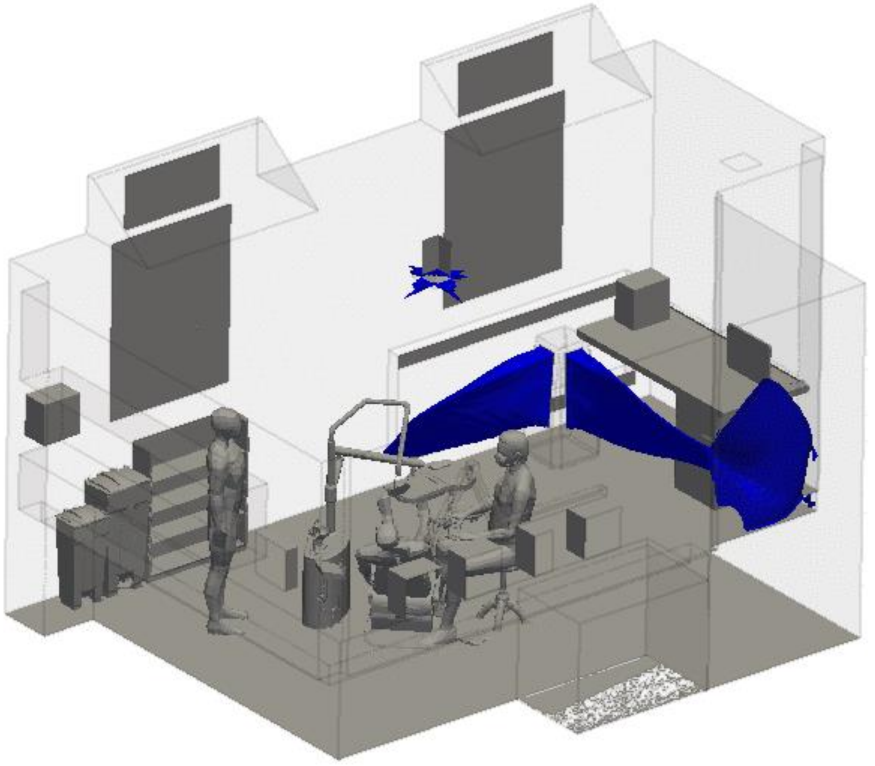
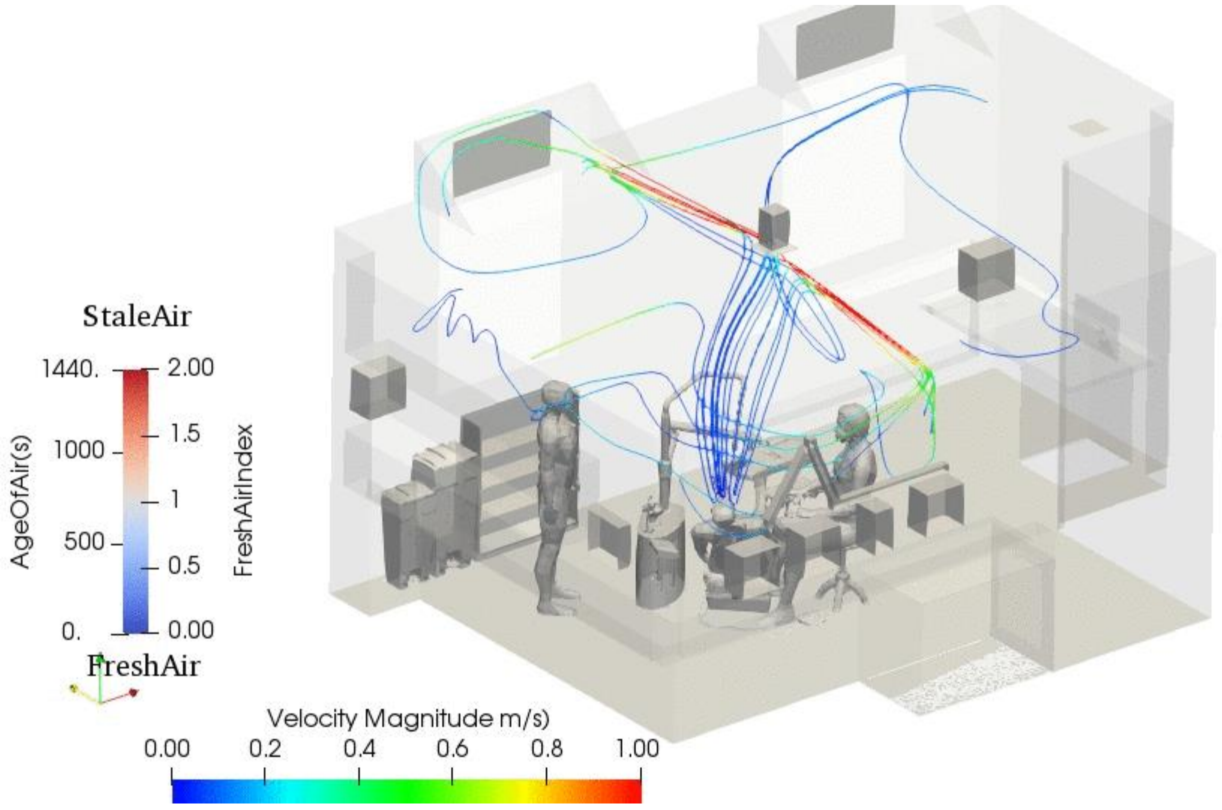
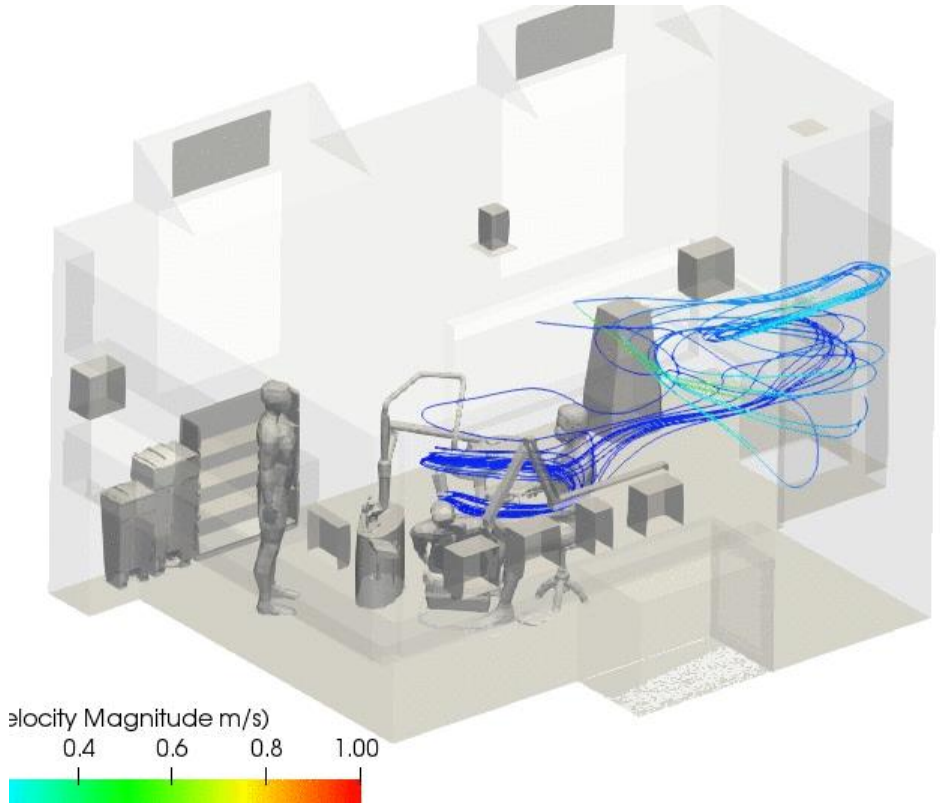


Dental Treatment Room - Fresh Air Index (streams from patient)

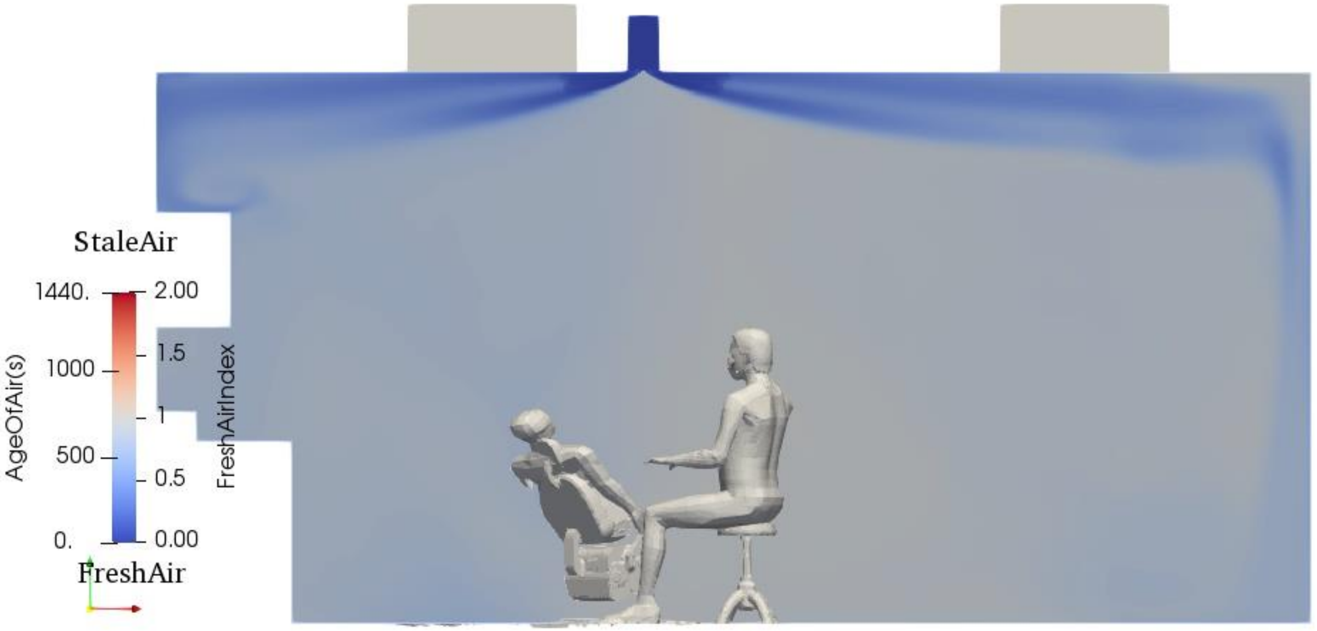
NO SCRUBBER Thermally neutral operating mode $360m^3/h$ POS-1





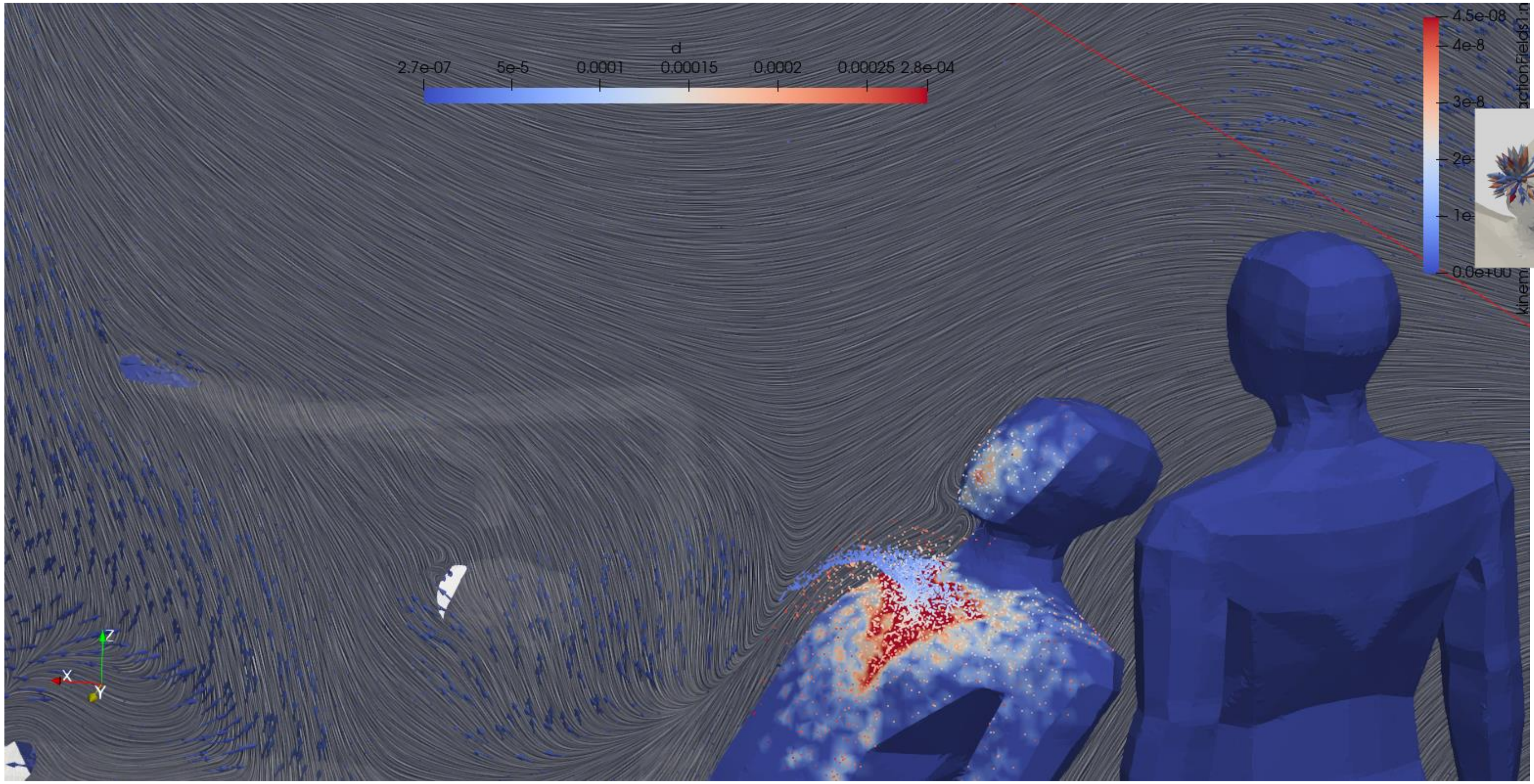
Dental Treatment Room – Fresh Air Index

NO SCRUBBER   Thermally neutral operating mode   360m³/h POS-1



Dental Treatment Room – Birmingham Children’s Hospital

Thermally neutral operating mode – **active droplets**



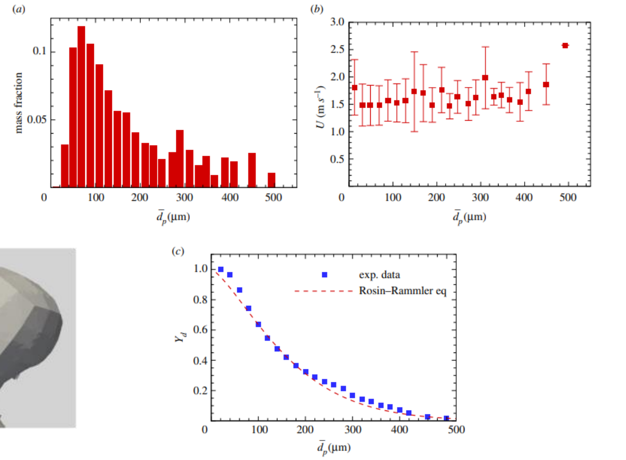


Figure 7. (*a*) Histogram of the droplet size distribution. (*b*) The velocity distribution of the droplets. (*c*) The Rosin–Rammler curve fitted for our obtained experimental droplet size data with a 29.5 ml min^{-1} flow rate.

INTERFACE

royalsocietypublishing.org/journal/rsif

Research

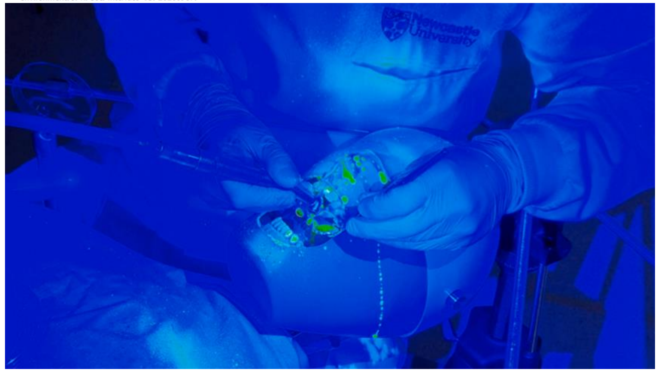
Aerosol formation due to a dental procedure: insights leading to the transmission of diseases to the environment

Parisa Mirbod[1], Eileen A. Haffner[1], Maryam Bagheri[1] and Jonathan E. Higham[2]

[1]Department of Mechanical and Industrial Engineering, University of Illinois at Chicago, 842 W. Taylor Street, Chicago, IL 60607, USA
[2]School of Environmental Sciences, University of Liverpool, Liverpool, UK

PM, 0000-0002-2627-1971; EAH, 0000-0002-8284-958X; JEH, 0000-0001-7577-0913

Cite this article: Mirbod P, Haffner EA, Bagheri M, Higham JE. 2021 Aerosol formation due to a dental procedure: insights leading to the transmission of diseases to the environment. *J. R. Soc. Interface* **18**: 20200967.

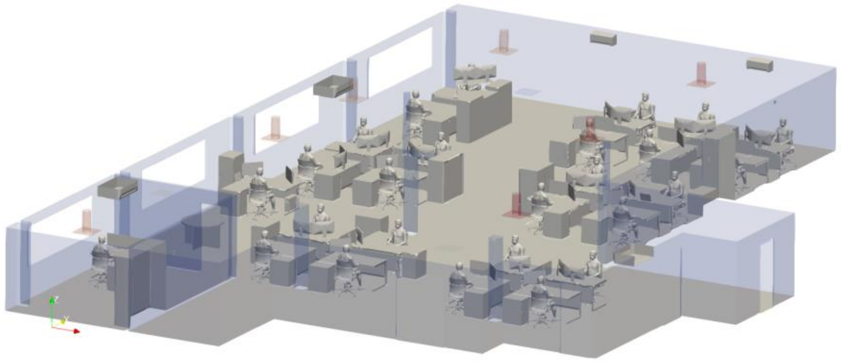


Open Plan Office (Elta Fans)

Preliminary: Neutral Operation

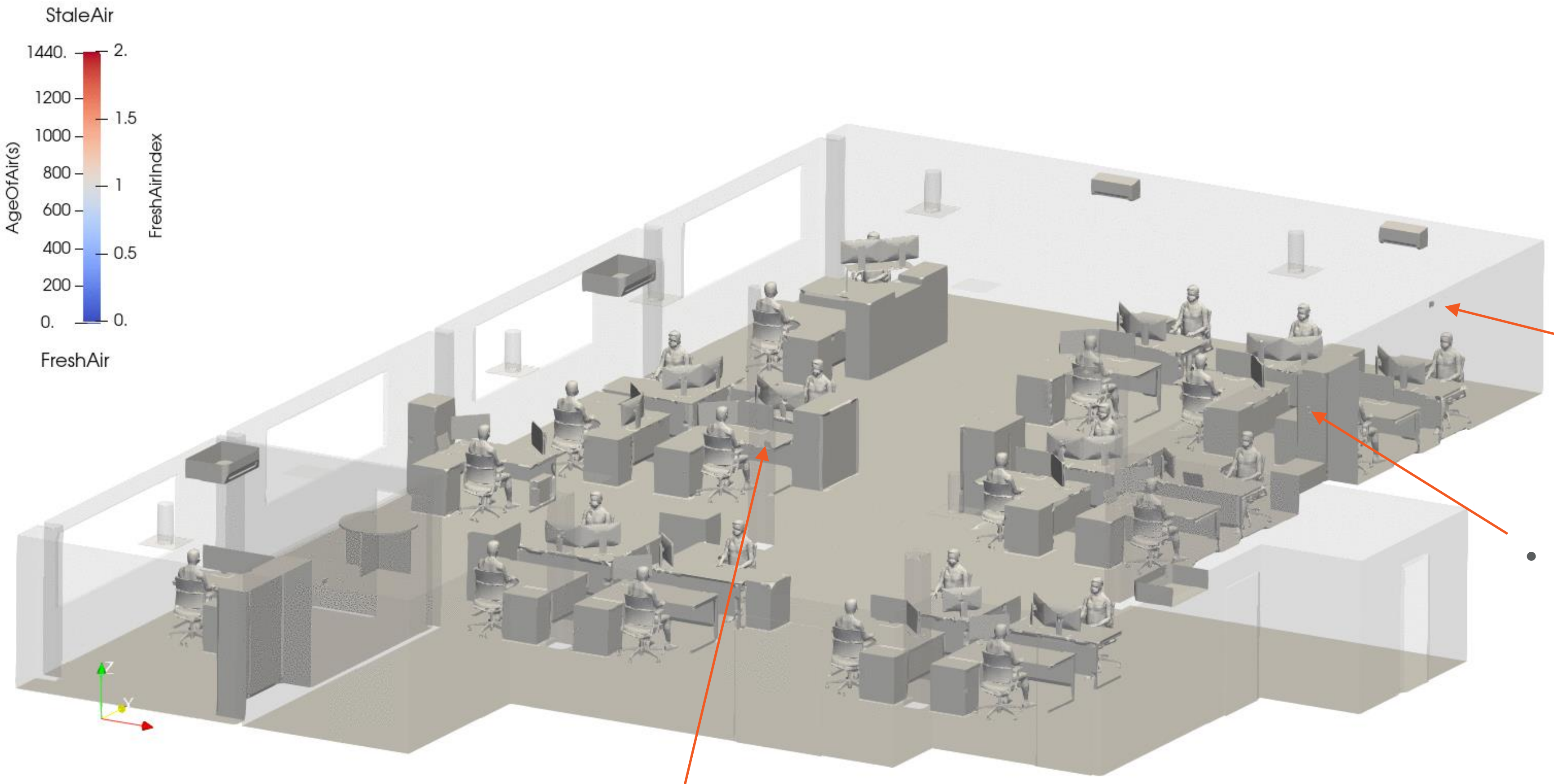
- Open Plan Office
  - 25 occupants in sitting position
  - Desk, cabinet, table
  - 1 CO_2 sensor and 2 Air quality sensor.
- Office-side
    - **3 Ceiling AC and 2 wall Ac units**
    - **(Neutral, Winter and Summer scenarios)**
  - Aims:
    - Establish good fresh-air circulation
    - Maintain temperatures for Occupant Comfort
  - Outcomes:
    - Community wellbeing
    - Engender confidence among attendance
    - Due diligence assessment by facility provider

- 3D-CAD provided by Elta Fans



FreshAirIndex

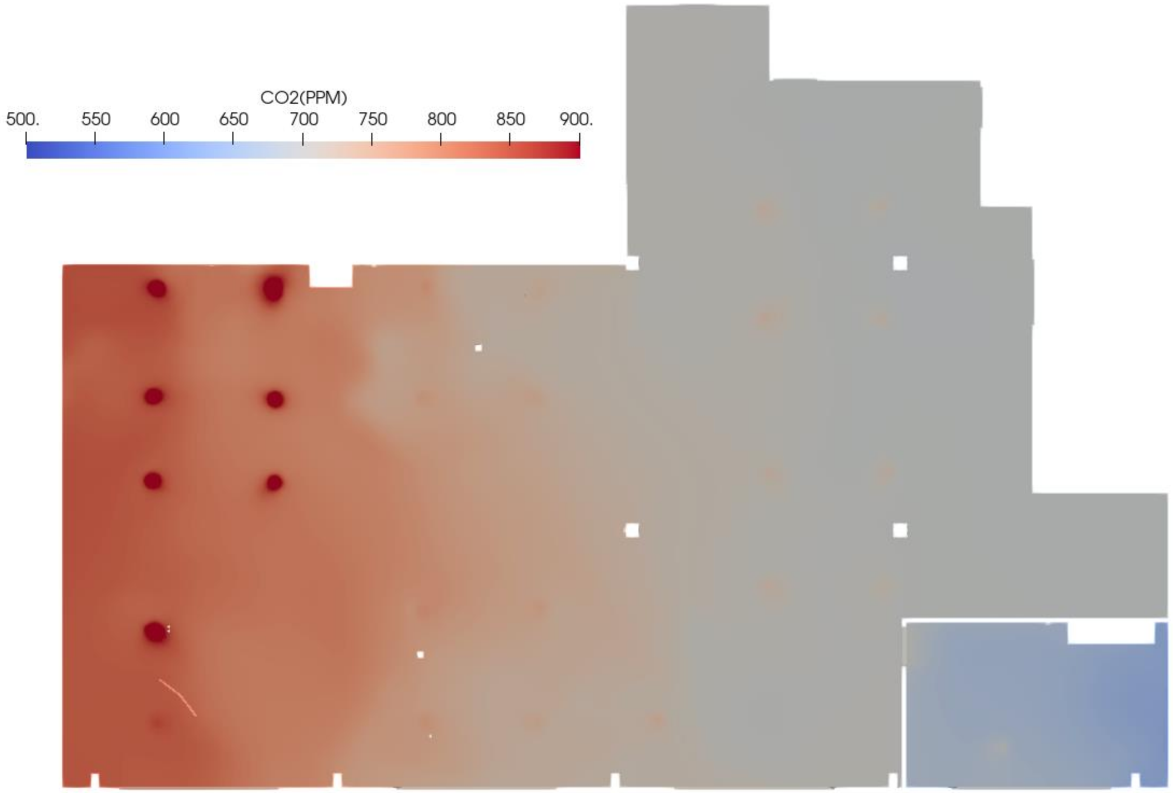
Z Sweep



- CO2 Sensor
- Air Quality Sensor
- Air Quality Sensor

Correlating CO_2 levels predicted vs measured

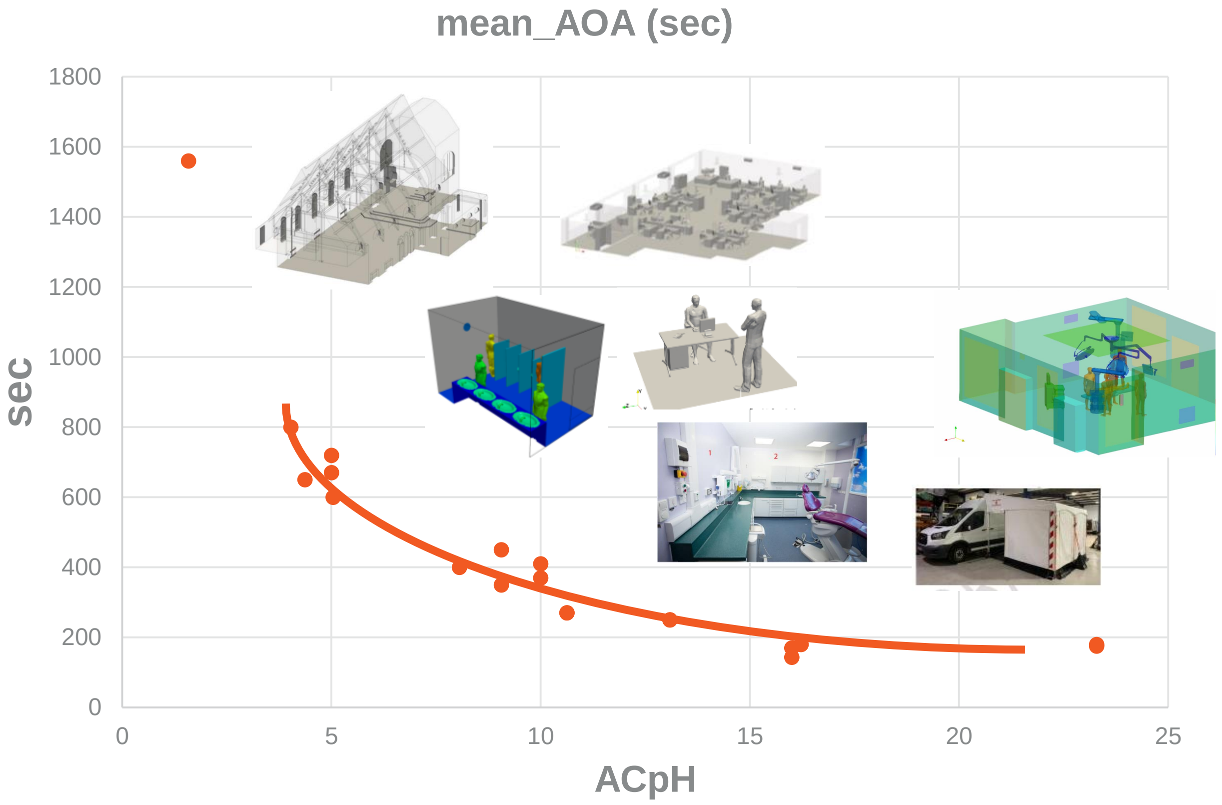
Multiple-occupancy large office

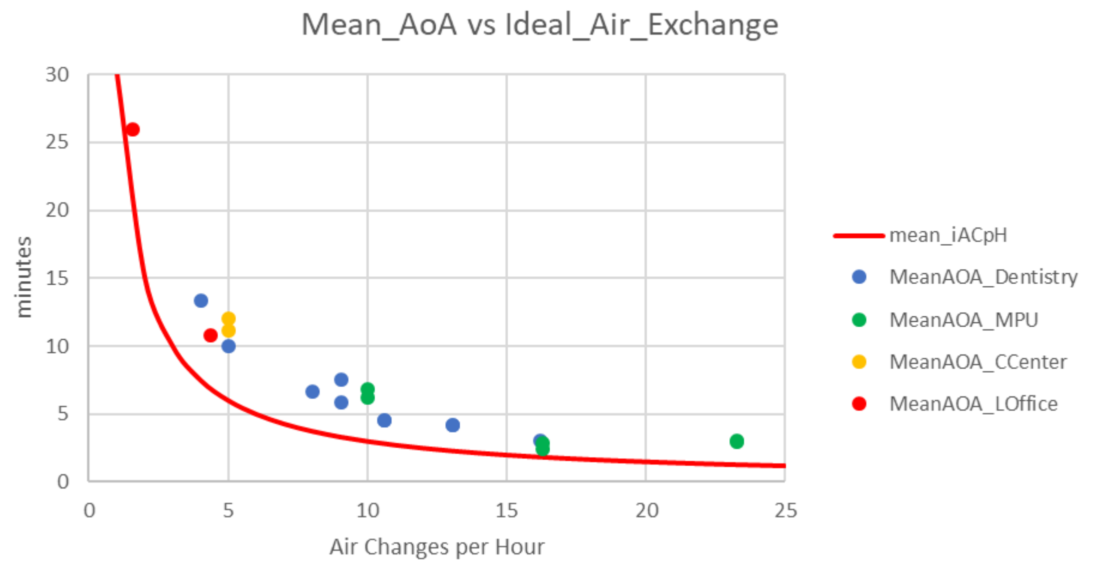


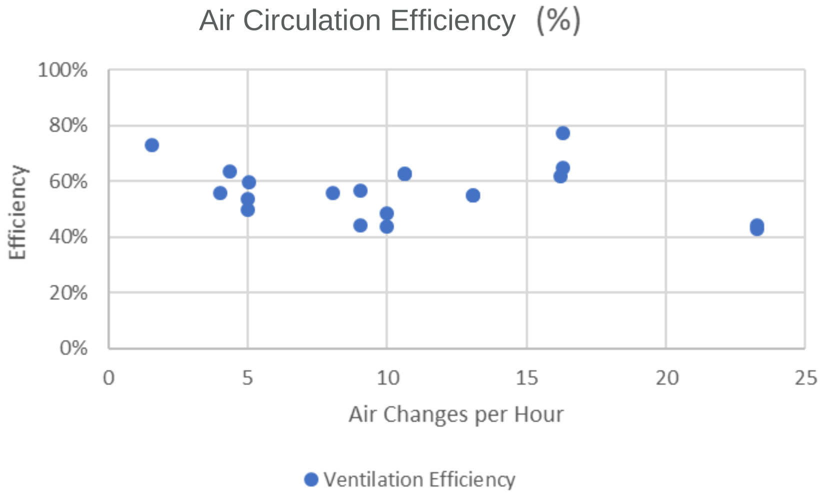
CFD (OpenFOAM®) in the COVID-19 battle

Summary

- Expanding CFD database of enclosures







CFD (OpenFOAM®) in the COVID-19 battle

Closing Statements

- **Are we ready for the next wave or pandemic**?

- Making CFD accessible to facilities providers (CFD non-experts)
  - CFD has been around for more than 50 years
  - It is deeply validated for several underlying physics and combinations of physics
  - We've learned about "interventions" in enclosed environments for health, wellbeing and safety
    - Measure
    - Mitigate
    - Optimise

- ***ventESI*** – Cloud App for non-expert CFD users
  - Available for testing now
  - Open to External partners between now and Autumn
- Innovate-UK project Nov20-Dec21 well under way
  - Several valuable stakeholder examples
  - Still open to include more "stakeholder" studies – please let me know

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